U.S. DEPARTMENT OF COMMERCE
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PB-286 198

A Systems Approach to Ecological Baseline Studies

Ecology Consultants, Inc, Fort Collins, CO

Prepared for

Fish and Wildlife Service, Fort Collins, CO Western Energy and Land Use Team

Mar 78

PB 286 198

Biological Services Program

[illegible]
MARCH 1978

A SYSTEMS APPROACH TO ECOLOGICAL BASELINE STUDIES

Interagency Energy-Environment Research and Development Program
Office of Research and Development • U. S. Environmental Protection Agency

Fish and Wildlife Service

U.S. Department of the Interior

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SPRINGFIELD, VA. 22161

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. FWS/OBS-78/21	2.	3. Recipient's Accession No. PB286198

4. Title and Subtitle
A Systems Approach to Ecological Baseline Studies

5. Report Date
March 1978

6.

7. Author(s) James B. States, Peter T. Haug, Thomas G. Shoemaker, Lanny W. Reed and Edward B. Reed

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Ecology Consultants, Inc.
P.O. Box 2105
Fort Collins, Colorado 80522

10. Project/Task/Work Unit No.
WELUT No. 001-76

11. Contract(C) or Grant(G) No.
(C) 14-16-0008-2119
(G)

12. Sponsoring Organization Name and Address
Western Energy and Land Use Team, Office of Biological Services
Fish and Wildlife Service, U.S. Department of the Interior
Drake Creekside Building, 2625 Redwing Road
Fort Collins, Colorado 80526

13. Type of Report & Period Covered

14.

15. Supplementary Notes

L.C. #78-600032; Coal Project; EPA-IAG-D6-E685

16. Abstract (Limit: 200 words)

The handbook describes a systematic approach to planning and conducting a "holistic" study of selected ecosystem components and functions, which are significant with regard to energy development projects in the Western United States. Techniques of ecological systems analysis are described, and the manual explains how to build a conceptual ecosystem model and use it to plan a baseline study. A glossary of key terms and an annotated bibliography are included.

17. Document Analysis a. Descriptors

environmental impact assessment
ecological studies
ecosystem analysis
systems analysis
ecosystem models
inventories and surveys

b. Identifiers/Open-Ended Terms

Western United States
baseline studies

c. COSATI Field/Group

18. Availability Statement

release unlimited

19. Security Class (This Report)
unclassified

20. Security Class (This Page)
unclassified

21. No. of Pages
411

22. Price
A18-A01

(See ANSI-Z39.18)

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

FWS/OBS-78/21
March 1978

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Coal Project
U.S. Fish and Wildlife Service
Contract No. 14-16-0008-2119

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Interagency Agreement Number
EPA-IAG-D6-E685

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Energy Coordination Staff
Office of Energy, Minerals
and Industry
Environmental Protection Agency
Washington, D.C. 20460

This study was conducted
as part of the Federal
Interagency Energy/Environmental
Research and Development Program
U.S. Environmental Protection Agency

Performed for

Western Energy and Land Use Team
Office of Biological Services
Fish and Wildlife Service
U.S. DEPARTMENT OF THE INTERIOR

i.a

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Library of Congress Catalogue Card Number: 78-600032

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PREFACE

This manual was developed by the project team after an intensive review of the existing literature on ecological baseline studies and extensive collaboration with practising environmental scientists. The collaboration culminated in two workshops, an early one focusing on a better conceptual framework from which baseline studies could be generated and a later one in which a draft of the manual was reviewed by its potential users. The intent of these interactions was to augment the judgment of the project team in a way that would facilitate wide acceptance of the manual, from both a theoretical and a practical standpoint.

In keeping with these objectives theoretical and practical material are separated in the manual. Chapter 1 presents the argument for a new point of view that can serve as a basis for generating better ecological baseline studies. Chapter 1, therefore, presents the "why" of the manual. It also serves as an executive summary. It briefly outlines the recommended approach that follows from the new point of view. It is expected that theoretical scientists, industrial managers, and agency administrators will be most interested in Chapter 1.

The remaining chapters (2 through 8) present the "what" for ecological baseline studies. These chapters present a detailed, step-by-step approach recommended for designing ecological baseline studies that meet the Chapter 1 criteria for better studies. The purpose of these chapters is to develop a general process for baseline study design. Because baseline studies are both site-specific and project-specific, this process addresses a general case and provides specific examples of how to apply the techniques. It thus remains for each project team to adapt and apply the methods to the specific needs of a given project with resourcefulness, creativity, and expertise.

To help bridge the gap between the general case and the particular energy development of interest to a user, we have provided specific examples, at different levels of resolution, from development projects.

Finally, it needs to be noted that the state of the art for designing and conducting ecological baseline studies is in a rapid stage of improvement. It is our hope that this manual will make a substantial contribution to that trend. However, in order to do this, the manual itself must be able to adapt to and promote such improvement. Therefore, each chapter is paginated independently, so that revisions may be incorporated periodically as they are needed.

EXECUTIVE SUMMARY

This manual develops an innovative approach to ecological baseline studies based on techniques of ecological systems analysis. The rationale behind the methodology is that ecology is an integrative science, and it should be approached as such. Chapter 1 explains this rationale in some depth, describing why the manual is needed and whom it was written for. It also presents an overview of the methods proposed in the manual.

Chapter 2 discusses the complex decisionmaking framework within which an ecological baseline study takes place and explains how to understand the many complexities (socioeconomic and legal requirements) using a logical, systematic approach to the problem.

Chapters 3, 4, and 5 tell the user how to build a conceptual model of the ecosystem and use the model to plan a thorough, focused baseline study that is specific for both site and type of development project. Details include how to compile and organize existing information, how to build a conceptual model from this preliminary information base, and how to select key ecosystem attributes to measure in a baseline study.

After determining which attributes to measure, the investigator can turn to Chapter 6 for an overview of field and laboratory methods used to study a broad variety of ecological parameters. Terrestrial and aquatic elements are discussed, as well as air quality, hydrology, habitat assessment, and soils.

Chapter 7 deals briefly with the planning and control of a field study, and Chapter 8 suggests ways of summarizing the data and information from the baseline study to be of most use to decisionmakers.

Additional aids to the manual user include three appendices: literature cited, an annotated bibliography of superior references, and a glossary of terms commonly used in ecological analysis and energy-development projects.

This report was submitted in fulfillment of Contract Number 14-16-0008-2119 by Ecology Consultants, Inc., P.O. Box 2105, Fort Collins, Colorado 80522, under the sponsorship of the Office of Biological Services, U.S. Fish and Wildlife Service. Work was completed as of 6 March, 1978.

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ACKNOWLEDGMENTS

A document as broad in scope as this requires inputs from many persons of varied disciplinary backgrounds. Thus it was that, in addition to more than a dozen writers, this manual was influenced, in one way or another, by more than 200 professional scientists throughout the United States. Many contributed literature, definitions, or time in writing suggestions.

An initial draft that pieced together the conceptual framework was reviewed by ecologists in a workshop in June, 1977. A rough draft of the manual itself was subjected to a similar workshop peer review in September. Participants in these workshops are listed at the end of these acknowledgments.

Project Manager Jim States directed the very complicated job of integrating all the inputs and authored Chapters 1 and 7. Peter Haug, as technical editor, had substantial input in revising and rewriting several chapters as well as authoring Chapters 3, 4, 5, and the statistics section of Chapter 6. Tom Shoemaker wrote Chapters 2 and 8, edited the glossary and annotated bibliography, and coordinated the details of final production. Edward Reed wrote the material on aquatic methods; he and Steve Martin served as technical reviewers of the final manuscript. Lanny Reed authored the section on terrestrial methods.

Special mention is due John Morrison, U.S. Fish and Wildlife Service Project Officer, for his meticulous scrutiny of, close concern for, and constructive suggestions about, several drafts of the manual. His contributions to all aspects of the project were many.

Others who had substantive input to parts of the manual, primarily to Chapter 6, are Charles Bonham (statistics and vascular plant methods); Jack States (soil microorganisms); Robert Kohut (glossary, air quality, and part of Chapter 4); Kent Kantz and Jack O'Hearn (hydrology); Russ Moore and Steve Long (soils); Michael Phelan, Denise Boschen, Kathy Twomey, Robert Kohut, Ed Reed, Lanny Reed, and Tom Shoemaker (annotated bibliography). Others who helped early in the conceptualization of the manual were Len Paur, Barbara Mihailjevich, Lynne Martin, and Tom Turner.

Finally, this document's value would be severely restricted, were it not for the support of several other persons. Sylvia Hardin provided able administrative assistance throughout a large part of the project. The responsibility for making each picture the equivalent of 1,000 words, or more, rests with Jim

Cripps, Barry Jobe, Michael Phelan, and Collin Fallat. And the bottom line, the ones who aided immeasurably in producing a prodigious amount of manuscript, were the production typists: Linda Holodick, Kellan Turner, and Rosemary McEwen.

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Laurence Jahn	Wildlife Management Institute
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Kent Keenlyne	U. S. Fish and Wildlife Service
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Roy Landstrom	U. S. Fish and Wildlife Service
Jeff Lee	U. S. Environmental Protection Agency
Robert Lewis	U. S. Department of Energy
Bruce Marker	Wyoming Game and Fish Department
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1.0 RATIONALE AND OVERVIEW

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> Does your involvement or interest extend to the development of energy resources in a way that maximizes economic return on investment yet minimizes damage to socioenvironmental systems?
>
> Do you agree with this statement? - "As presently conducted, predevelopment baseline studies are nearly useless. The information gathered in the course of such studies has little influence toward environmentally sound decisions about proposed or existing energy developments."

If the answer to one or more of these questions is "yes," then this manual has something of use to you.

1.1 WHAT DOES THIS MANUAL DO, AND FOR WHOM?

This manual attempts to define and standardize a holistic approach to ecological baseline studies for energy conversion projects in the western United States. The need is urgent. The energy resources of the western United States are vast and varied. They include coal, oil shale, natural gas, petroleum, uranium, sunlight, and geothermal resources. Vigorous development of several of these resources is already proceeding, with new extraction, conversion, and transmission projects underway. President Carter's proposed National Energy Plan focuses more attention on the West, urging a shift from petroleum to coal, the supplementary use of nuclear power, and the "vigorously expanded" development of "new unconventional sources of energy" (U.S. Senate Committee on Energy and Natural Resources 1977). Clearly, energy-development activities in the western United States will rapidly expand in the coming years.

Rapid development increases the risk of serious damage to the environment. The direction of this large-scale energy development in a way that is both socially and environmentally acceptable is a major national challenge. This manual is offered as a tool to help those involved in energy-development decisions meet that challenge.

We must recognize some existing realities. First, there are serious deficiencies in the present process of gathering information on social and environmental systems. This process needs to be improved. Second, the decision processes and time frames for energy developments are often not designed for properly incorporating the results of ecological or other socioenvironmental baseline studies.

There are two principal groups involved in the energy development process and they often operate as antagonists: those who want to develop our energy resources (sometimes at any cost to the environment) and those charged with the managing of our natural resources (sometimes at any cost to the economy).

Costs of energy development are high and a developer must cut costs wherever he can. It is to be expected that socioenvironmental researchers (including ecological-study participants) will do only that minimum of environmental work necessary to obtain construction and operation permits. Government agencies, on the other hand, are responsible for the wise use of our natural resources and for protecting society from unnecessary and unacceptable damages to social and environmental systems. In order to do this wisely, they must have a certain minimum of socioenvironmental information. It is the responsibility of the developer to provide that information.

We believe that antagonism between these two parties is not only unnecessary, it is detrimental. We recommend instead a "win-win" approach to energy development problems. This document defines an approach that permits decisionmakers to get the information they need and industry to spend only what it must to provide that information. Through cooperation, rather than antagonism, industry can maximize the useful data derived per dollar while government does a better job of rendering decisions that are environmentally sound. If, by the application of this approach, we can also speed up the process of reaching those decisions, our whole society will benefit.

In keeping with this philosophy, it is intended that this manual will have wide utility among all parties concerned with energy development and its effects. However, it will be most useful to four principal groups: industrial managers, agency administrators, industry field staffs, and agency field staffs. The usefulness of the conceptual framework and the utility of the recommended process for influencing better decisions in an economical fashion will be of interest both to industrial managers and to agency administrators. Industrial managers will dictate what will be done in most baseline studies; agency administrators will accept or reject the resulting information. The recommended step-by-step approach to designing and conducting baseline studies will be of greatest interest to the two groups who must implement the process - the industrial or agency field staffs charged with designing, conducting, and/or evaluating ecological baseline studies.

The training and philosophies of these four groups may differ greatly, making the style of presentation in the manual a difficult but important problem. Basically they can be narrowed to two categories: managers and technical staff. Project managers for baseline studies must have day-to-day contact with both the requirements of the administrator (agency and industrial) and the scientific and technical concerns of the field staff. It is their job to see that the information needs and guidelines of the administrators are met, but in a technically and economically sound manner.

Thus, the manual is fundamentally directed at baseline-study project managers and their technical staffs. It is written at two levels in most chapters. Each chapter that describes a step in the process begins with an introduction and overview. This section explains the rationale behind the prescribed methodology somewhat as a textbook. The remainder of each chapter is a manual that outlines concisely the step-by-step procedures explained in the introduction. In this way, the technical staff will not have to read explanatory material if they do not wish to. However, the introductory material is there to serve as a ready reference and explanation for the procedures that the staff will actually follow.

1.2 WHY IS THIS MANUAL NEEDED?

The rationale expressed earlier for a cooperative approach to baseline studies sounds very well and good. The problem is that it seldom happens that way. There is widespread disagreement about the purpose and methods of ecological baseline studies. As a result, ecological baseline studies have lacked standardization, often failing to agree in scope, content, comprehensiveness, methodology, and choice of parameters recommended for comparable situations. Terminology lacks universal definitions. Biologists, economists, engineers, agencies, and laymen disagree among and between groups over definitions of ecological phenomena, developmental processes and impacts, and reclamation practices. Analyses tend to emphasize primary, short-term impacts caused by development while ignoring secondary and chronic effects. Realistic, comprehensive definitions and guidelines for conducting baseline studies and communicating the findings have been largely unavailable. A common fault of ecological baseline studies is their tendency to be ends in themselves rather than carefully designed means to influence the planning of the development and to facilitate postdevelopment monitoring of impacts. They often contain much life-history detail on conspicuous species but fail to characterize quantitatively the workings of the overall ecosystem involved. Field techniques employed are sometimes inappropriate or are applied inadequately.

1.2.1 How Baseline Studies Can Be Improved

There has been much argument over how to perform the special kind of inventories termed "environmental or socioenvironmental assessments." This is particularly true for proposed energy development, especially those parts of the assessments referred to as ecological baseline studies. In the course of preparing this manual we found a remarkable new convergence of professional thinking about how to do the job better. The most illuminating of these perceptions are summarized as follows:

> Perception #1 - Environmental scientists are responsible for entering ecological information into the decisionmaking process.
>
> Environmental biologists are now showing a growing awareness of their failure to anticipate the needs of the decisionmaking process. They are starting to push for better ways of implementing

their information into that process. There is an increasing awareness that ecological baseline studies should provide a good basis for the prediction of environmental effects and that these effects should be ". . . described in terms that will make sense to the reviewers of the assessment. In particular, these effects should not be described exclusively in terms of chemical, physical, or biological parameters. Rather, potential impacts should be addressed in terms that relate to their implications to social well-being, land-use potential, or to changes in resources or characteristics of the environment that may be considered worth preserving, conserving, or enhancing" (Dickson et al. 1975).

Perception #2 - There is a need to judge the biological significance of anticipated effects.

It would be irresponsible to continue to duck the issue of biological significance for effects we predict from proposed actions. Even though it may leave us more exposed to legal action, it is the environmental scientist, not the decisionmaker, who is in the best position to make such judgments. In a recent workshop on this subject it was concluded that " . . . an impact is significant if it results in a change that is measureable in a statistically sound sampling program and if it persists, or is expected to persist, more than several years at the population, community, or ecosystem level" (Sharma et al. 1976). The social-"acceptability" of such impacts is a judgment to be made by lawmakers and other decisionmakers in each specific case on the basis of relative costs and benefits to society.

Perception #3 - There is a need to apply better science to environmental problems.

There is also growing recognition that present techniques for designing ecological baseline studies are inadequate. Once the needed ecological input has been defined, a clear statement of objectives for providing that input needs to be made. As stated by Eberhardt (1975), ". . . our central problem is defining the objectives for a particular site survey." This theme was emphasized and extended in a consensus paper presented at a recent Council of Environmental Quality Symposium wherein it was advocated that if ecological baseline programs are designed to test suitable hypotheses, and if the experimental design includes adequate consideration of environmental variability, replication, and adequate sample size, then our capabilities for making predictive impact assessments will be significantly improved (Buffington et al. 1976). It is essential that the available tools of experimental design and statistical tests be applied in meeting baseline-study objectives (Eberhardt 1976; Zar 1975).

Next, there is growing awareness that the ecological questions that address those objectives need to be formulated in a rigorous hypothesis-testing framework. Current studies fail to provide the quantitative data base essential to ecologically sound planning and decisionmaking. Clearly, ecological parameters and methods for measuring them must provide a statistically valid quantitative data base appropriate to the needs of impact assessment, mitigation planning, and long-term monitoring.

Qualitative methods can still be useful, however, particularly in the information-gathering and alternate-site-evaluation phases of baseline definition. Qualitative on-site surveys will be a necessary basis for defining the geographic and temporal limits of the systems to be investigated by the baseline studies. Selection of parameters to be quantitatively investigated on a specific site should be at least partially based upon making the best use of information already available, including knowledge of the kinds and distribution of major vegetation types, common plant and animal species, and the presence of unique habitats and rare or endangered species.

Perception #4 - There is a need to design studies and interpret data by identifying clearly the biological level of organization from which inferences will be made.

An ecologist wishing to make inferences about biological systems must identify the most appropriate level of biological organization and make observations at that level. A general principle that could be widely applied is that if we wish to have explanations for what we observe we should look to the next lower level of organization for causative mechanisms. If, on the other hand, we wish to make statements as to the "significance" of our observations we should do so from the perspective of the next higher level of organization (Cooper 1976).

Most ecological baseline studies have been focused at the species level of organization with little regard for the total system. Yet the presence or absence of a species or a change in population size of a specific species is an inadequate basis for assessing effects of man's activities on surrounding ecosystems (Perkins 1975). This approach assumes the decomposability of ecological systems. However, ecosystems are relatively nondecomposable and must be investigated from an integrated system perspective (Bella and Overton 1972).

It has been stated that the baseline study approach is probably of quite limited value unless it is an integral part of a much larger effort to address ecosystem characteristics and dynamics. But it is not practical to predict impacts for each ecosystem state available. Rather, the professional ecologist - given constraints of cost, time and uncertainty - bears a responsibility in selecting the temporal scale, spatial scale, and level of biological organization to be used in assessing the environmental impact of the project (Hirsch 1976).

Perception #5 - There is a need for a new perspective from which to design ecological baseline studies.

Odum and Cooley (1976) not only agree that the inadequacy of most baseline studies stems from focusing on the wrong level of organization but also suggest an alternate approach. They suggest that environmental impact assessment should shift from component analysis (where factors and organisms are treated as independent entities with no interaction function) to more holistic approaches (where interaction and integrative functions are also involved). Barret et al. (1976) also advocate a more holistic approach in ecological investigations and suggest that the scope of investigation be balanced in order that both structural and functional data are available to analyze the system as a whole.

As a direct result of the above considerations a consensus is emerging that the selection of "what to measure" in ecological baseline studies should be approached from a holistic perspective. This approach has been eloquently advocated for some time by systems ecologists (Van Dyne 1966) but is only now gaining wider acceptance (Bella and Overton 1972; Odum 1977; Barrett et al. 1976).

A natural outgrowth of this trend is a renewed interest in using conceptual models to organize thinking about which parameters most need to be measured. A case is strongly argued by Cooper (1976) that two strategies for environmental protection are open to us. The simplest is to monitor the behaviors of specific indicators to assess damages and then to compensate for them. However, once experienced, the losses may not be compensable (extinction of a species, for example). Thus, the cost of being wrong via this feedback control is too costly. An alternative to the feedback "experiencing" of damages is a "feed forward," or predictive control process. This requires developing a valid functional model of the biological system, monitoring the critical aspects of the physical environment, and then anticipating the behavioral characteristics of the system under anticipated perturbations. Development of conceptual models by which we can formulate, communicate, and improve our understanding of ecosystem functioning has been recognized by a wide variety of authors as an essential early step in this foresightful decisionmaking process.

1.3 HOW DOES THE MANUAL APPLY THESE PERCEPTIONS?

Although the perceptions described above are widely held among practicing environmental scientists, they have not been widely applied. To be implemented they must first be explicitly defined and communicated as a common set of standards, as a new perspective from which better ecological baseline studies can be generated. The following operational definition and underlying assumptions is a statement of the perspective from which this manual is written. It is intended as a vehicle for standardizing the point of view from which ecological baseline studies are designed. This standardization should facilitate the entire baseline-study process.

1.3.1 Recommended Perspective for Future Ecological Baseline Studies

Fundamental to any operational definition for ecological baseline studies is an understanding of the origin and legal basis for the term baseline.

Ecological baseline studies are rooted in the National Environmental Policy Act (NEPA) (Public Law 91-190, 91st Congress, January 1, 1970). Section 102(2)(C) of PL91-190 requires that federal agencies include, in every recommendation or report on proposals for legislation and other major federal actions that significantly affect the quality of the human environment, a detailed statement on:

1. The environmental impact of the proposed action.
2. Any adverse environmental effects that cannot be avoided should the proposal be implemented.
3. Alternatives to the proposed action.
4. The relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity.
5. Any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented.

These topics are to be addressed in an environmental impact statement (EIS) generally prepared by a federal agency. The origin of the term "baseline" is obscure, but is usually meant to include the development of an information base sufficient to enable the agency to adequately address the five topics mentioned in Section 102(2)(C). Subsequent to enactment of PL91-190, the Council on Environmental Quality has published guidelines for federal agencies preparing EIS's, and several agencies have issued guidelines specific to their requirements. However, the basic five topics remain as specified in the original NEPA.

Although the term baseline may have originated from NEPA, it has since come into broader use. Frequently, federal regulatory agencies require applicants to develop information concerning the environmental consequences of granting a desired permit. State agencies may be in a position either of developing an EIS for a project involving federal land or grants or of requiring that an applicant submit environmental data. In these contexts, the baseline data are used in a formal, clearly discernible product, i.e., EIS or permit application. Baseline may also refer to an informal assembling of data in-house for use in management decisions by federal or state agencies; more rarely, industrial establishments may perform baseline studies to help evaluate consequences of alternative developments.

Thus, the term baseline has been popularly used on several levels of meaning without having been specifically mentioned in the legislation that gave rise to the necessity of obtaining baseline data.

An operational definition for ecological baseline studies comprises two elements - a summary statement and a set of assumptions. The defining statement is based on what an ecological baseline study should be; the assumptions explicitly state the objectives implied in the definition.

1.3.1.1 Operational Definition for Ecological Baseline Studies. For the purposes of this manual, an ecological baseline study is any investigation conducted prior to the breaking of ground in order to provide an ecological basis for decisions on whether, where, and how to develop energy resources. The scope of study may range widely, from qualitative inventories conducted by natural resource managers to exhaustive quantitative studies of specific energy-development sites undertaken by industry in compliance with federal and state regulations. The results of an ecological baseline study describe the existing ecological conditions and trends in the potentially affected region, providing a reference baseline from which environmental scientists can (1) predict the effects of the proposed action and recommend alternatives, (2) define appropriate mitigation measures, and (3) design future programs to monitor the accuracy of predictions and the effectiveness of mitigations.

1.3.1.2 Assumptions Underlying the Operational Definition. This manual defines a process for tailoring ecological baseline studies to a wide variety of specific energy developments while meeting established criteria for sound baseline studies. Because ecological baseline studies are only a part of the socioenvironmental assessment process, such studies are affected substantially by influences external to the studies themselves. These outside factors include:

- Other socioenvironmental studies being performed.
- Political and legal requirements to be met.
- Specific features and time-staging of the proposed energy development.
- Development planning and engineering.
- Stages of the decisionmaking process requiring ecological input.
- How the baseline data will be used in the construction, operation, and termination phases of an approved energy development.

For example, (1) the identification of permeable strata in geotechnical studies may dictate an emphasis on biological effects of leachates contaminating surface waters down-slope from the development; or (2) frequent temperature inversions detected by atmospheric studies may call for increased emphasis on the biological effects of gaseous emissions; or (3) water resource studies may reveal a general lack of surface water in a region, thereby requiring greater emphasis on a few surface water bodies as critical habitats in the ecological studies. Most important is the interfacing of ecological baseline studies with engineering design studies. Impact predictions will be accurate only to the extent that the best possible biological knowledge is combined with detailed engineering plans in the presence of good professional judgment.

Assumption #1 - Baseline studies will be conducted from a holistic viewpoint.

A holistic point of view is one that considers not only the total ecological systems within a potentially affected area, but also the political, legal, and socioeconomic considerations that will be used to judge the significance of impacts upon those systems. This point of view is essential to sound ecological baseline studies. All of those things that are not a part of an ecological baseline study, but which may importantly influence its scope and timing, are referred to as the decisionmaking framework. The study is performed within this framework and should be responsive to it. Definition of this framework is a necessary precursor to, and basis for, the first step in designing an ecological baseline study: establishing the purpose, goals, and objectives of the study.

Assumption #2 - Baseline studies should provide a basis for predicting and verifying impacts.

Protecting environmental values from irreparable harm requires a predictive rather than an "experience-it-and-see-how-bad-it-gets" mode of responding to environmental impacts (Cooper 1976). With accurate tools for predicting and verifying effects we will be able to apply ecological foresight to energy developments, mitigate potentially serious effects, and then monitor to assure that mitigation procedures are effective. Conceptual models showing how we believe ecological systems operate are assumed to be essential tools in this process of developing predictive tools.

Assumption #3 - The central purpose for ecological baseline studies should be to provide the best possible input to energy-development decisions.

The best possible input is usually constrained by available time and money. In general, the level of effort (time and money) for a given baseline study should depend on the potential for ecological damages (especially damages associated with economically or aesthetically valuable resources). On most energy development projects, it is assumed that ecological input is required on decisions dealing with alternate site selection, engineering-plan modifications, facility construction, facility operations, and the eventual closing down of operations.

Assumption #4 - There is a need to apply better science to environmental problems.

The principal focus of the baseline study design process is on what to study and how to study it. However, the answers to these questions must be preceded by an answer to the question: why do a study at all? Often when science finds itself having difficulty providing the needed answers, it is because the proper questions have not been asked. Therefore, it is necessary to take a systematic approach that resolves into at least three basic steps:

1) Ask the right questions. Find out what really needs to be known to facilitate environmentally sound decisions.

2) Translate the information needs into specific statements of objectives for a study program and apply the best techniques science has to offer in fulfilling these objectives. Whenever possible, the objectives should be met (1) by framing good, specific, testable hypotheses about how we think industrial developments may affect local ecosystems, (2) and by designing elegant experiments to test our predictions.

3) Put the information obtained from the study into a format that is useable by decisionmakers and get it into the most effective decision channels in time to influence the decisions.

Assumption #5 - Baseline studies encompass only a portion of the total ecological study program, and provide input only to specified decision phases.

The operational definition for ecological baseline studies must be sufficiently broad to encompass the wide variety of energy developments that may occur in the western United States. The scope of such studies may be defined in terms of their content and the uses to which their results are to be put in the decision process.

Study Content. Potentially, a total ecological study program for an energy development could include eight major phases.

1. Review of existing literature and site inventory.
2. Detailed ecological description of the site.
3. Establishment of statistically valid benchmark measurements.
4. Preliminary development of mitigation measures and monitoring programs.
5. Basic research into the response of natural systems to measured perturbations.
6. Construction-stage monitoring and mitigation.
7. Operational monitoring and mitigation.
8. Postoperational monitoring of ecological recovery.

In this manual, the term ecological baseline studies will be restricted to Phases 1 through 4, largely excluding basic research and impact-mitigation/monitoring phases. However, to the maximum extent possible, an ecological baseline study should recognize the other phases of a complete ecological studies program by identifying areas of needed basic research and providing preoperational data that will be maximally compatible with eventual monitoring programs.

Study Output. In general, ecological baseline studies should be designed to provide output to the following decision phases of development:

- Selecting the development site from a number of alternatives based upon (1) preliminary engineering designs and plans for facility operations and (2) existing information about each siting alternative plus results from qualitative site surveys.
- Planning preliminary facility design and location on the selected site. At this stage the emphasis of ecological studies should be on identifying major potential problems associated with gross features

of facility location and design. These judgments will be based upon (1) a comprehensive description of the existing environment and (2) identification of likely critical interactions between development plans and biota or physical parameters that are linked to important biological, economic, or social values.

- Drafting final plans for facility location and design. At this stage the potential effects of all details of the planned development should be reviewed in light of all information obtained from ecological baseline studies so that needed adjustments can be made in the development schedule and technical plans. This will represent the final input of baseline data to the decision process prior to facility construction.

Assumption #6 - Certain constraints limit what is possible
in ecological baseline studies.

Although ecologists often want to study every possible aspect of potentially affected ecosystems over the maximum possible time period, several practical constraints severely limit what is possible.

Levels of Resolution. Ecological baseline studies may encompass many levels of resolution, as measured along a variety of dimensions. Field studies may be more or less extensive, depending upon the information already available through the literature and local experts. Most important in determining the level of resolution is the potential seriousness of anticipated impacts: In general, an ecological baseline study should identify and concentrate upon those ecological effects that are biologically, politically, legally, and socially of greatest concern. The level of effort to be expended upon these will be a function of both the degree of concern and the overall size of the project.

Baseline studies must also be adaptable to various geographic scales and to different degrees of energy-development intensity. Essentially, baseline studies must be employed practically for at least two basic development situations:

- The approach should be amenable to a site-specific, development-specific situation; in this case, the baseline study should be geared toward specific decisions (e.g., site selection, remedial environmental control plans such as reclamation plans, and resource-management decisions).

- The approach should also be amenable to allow study of "generic" developments that could be located anywhere within a broad region; in this situation, baseline studies should establish the ecosystem components and relationships that are common to a set of generic developments.

Time Frame. Time may influence the scope of baseline studies in at least two important ways. First, the duration of impacts and the length of time required for their manifestation may importantly influence baseline study designs. In general, the most serious types of impacts are those that take the longest to become detectable (chronic as opposed to acute) and exhibit the greatest persistence (long-term as opposed to short-term impacts). Unfortunately these are also the most difficult impacts to predict.

Second, the time frame of baseline studies must be defined so as to maximize the influence of study results on the decision process. However, biological phenomena tend to change radically from season to season and year to year. These variations must be considered in any description of the existing environment developed as a basis for energy-development decisions. Here is where science is most at odds with the decision process. By the time the one-to-several-years of needed baseline data have been accumulated, most of the critical energy development decisions have been made. Although there are signs that the decision process is moving toward a better synchrony of decisions with the availability of information, there is at present a practical limit on how far this can be forced. For example, the decision to develop has usually been firmly made before ecologists are consulted. It is therefore unlikely that ecologists can influence the decision to initiate an energy development. However, they should be able to time and structure their input to help answer questions like, "Where is the best place?" and "What is the best way?". Sometimes ecologists may even be able to provide a data base for decisions on whether or not the development ought to proceed at all. As a general rule, biological information needs to be considered in the decision process sooner, wherever possible, even at the risk of not having all information ecologists would like to have.

For example, a process ought to be defined for obtaining "soft" information quickly for alternate site selection and, once the development site has been chosen, for obtaining hard data over a longer period for establishing benchmark information and for input to facility location and design. It is necessary to distinguish between the kinds of soft data that are useful as early input to facility design and the kind" of hard data needed as a benchmark against which to assess ecological effects during facility operations.

The State of the Art. Although many components and processes may be identifed as ecologically important, and the energy development of interest is expected to have significant effects upon them, only those having observable parameters that are measurable by existing methods can be included in present ecological baseline studies. If other important parameters that we cannot presently measure are identified from the holistic, ecosystem-modeling point of view advocated herein, then important needed research has been identified.

Experimental Design and Statistical Analysis Constraints. Even if a potentially affected parameter is measurable by available methods, its utility to a baseline-study program often depends upon our ability to gather data that meet certain constraints of experimental design and statistical analysis. Thus the methods must provide adequate information for the determination of statistical reliability, accuracy, precision, and sensitivity, and they must be amenable for use in experimental designs by which man-induced effects can be separated from naturally occurring changes.

Cost Effectiveness. Any ecological baseline study, whether it is for a resource inventory or an impact assessment, must be designed with consideration for the manpower and money available to do the job. In general, the resources available will be no more (and are often less) than the minimum that is required by the decision process. It is therefore contingent upon the baseline study designer to get the most for his money by studying those elements of ecosystems most pertinent to the decision process and by using those methods that are most cost effective in obtaining adequate data.

1.3.2 Steps in Performing a Baseline Study - An Overview

Although the operational definition and underlying assumptions form a statement of the recommended point of view for future baseline studies, they do little to provide the "how-to" information on designing and conducting an actual study. Chapters 2 through 8 of this manual set forth detailed procedures for performing ecological baseline studies. This section summarizes these procedures in an overview.

1.3.2.1 The Energy Development Program. Fundamental to this approach is the understanding of the context in which the ecological baseline study occurs: The ecological studies are only a part of a total energy-development program. Figure 1-1 illustrates the relationship between the ecological baseline study and the other, equally important elements of the overall program.

As Figure 1-1 shows, the energy development program can be functionally divided into two distinct elements. At the top of the diagram are the major phases of an energy-development program, and the decision milestones that mark the major phases. Underneath the project phases are the sources of information needed for planning the development and for making socially and environmentally sound decisions. These sources include a variety of study programs, one of which is the ecological studies program. Vertical arrows in Figure 1-1 portray important information exchanges between the various study programs and between the study programs and the decisionmaking process.

Figure 1-1 also shows that the ecological baseline study is just a portion of the total ecological studies program for an energy development. The baseline study begins early in the program and ends about the time when final engineering plans are prepared. At this time, monitoring and mitigation planning begins. These are followed by a monitoring program that extends through the life of the project.

1.3.2.2 The Major Steps in the Baseline Study. In Figure 1-1 the ecological baseline study is presented as a "black box" within the overall energy-development program. Figure 1-2 opens up the black box and illustrates the seven major steps defined in Chapters 2 through 8. Figure 1-2 also indicates the manual chapters in which these steps are presented. The following discussion provides a brief introduction to each step, and thus serves as a broad overview of the content of the rest of the manual.

Step # 1 - Define Decisionmaking Framework (Chapter 2)

Each energy-development project occurs within a unique decisionmaking framework. This framework consists of (1) the plans of the developer and his technical project team (including biologists); (2) the concerns of agencies and other interested parties who provide commentary and affect decisions about the project team proposals; and (3) the legal and formal procedures and protocols by which decisions will be reached.

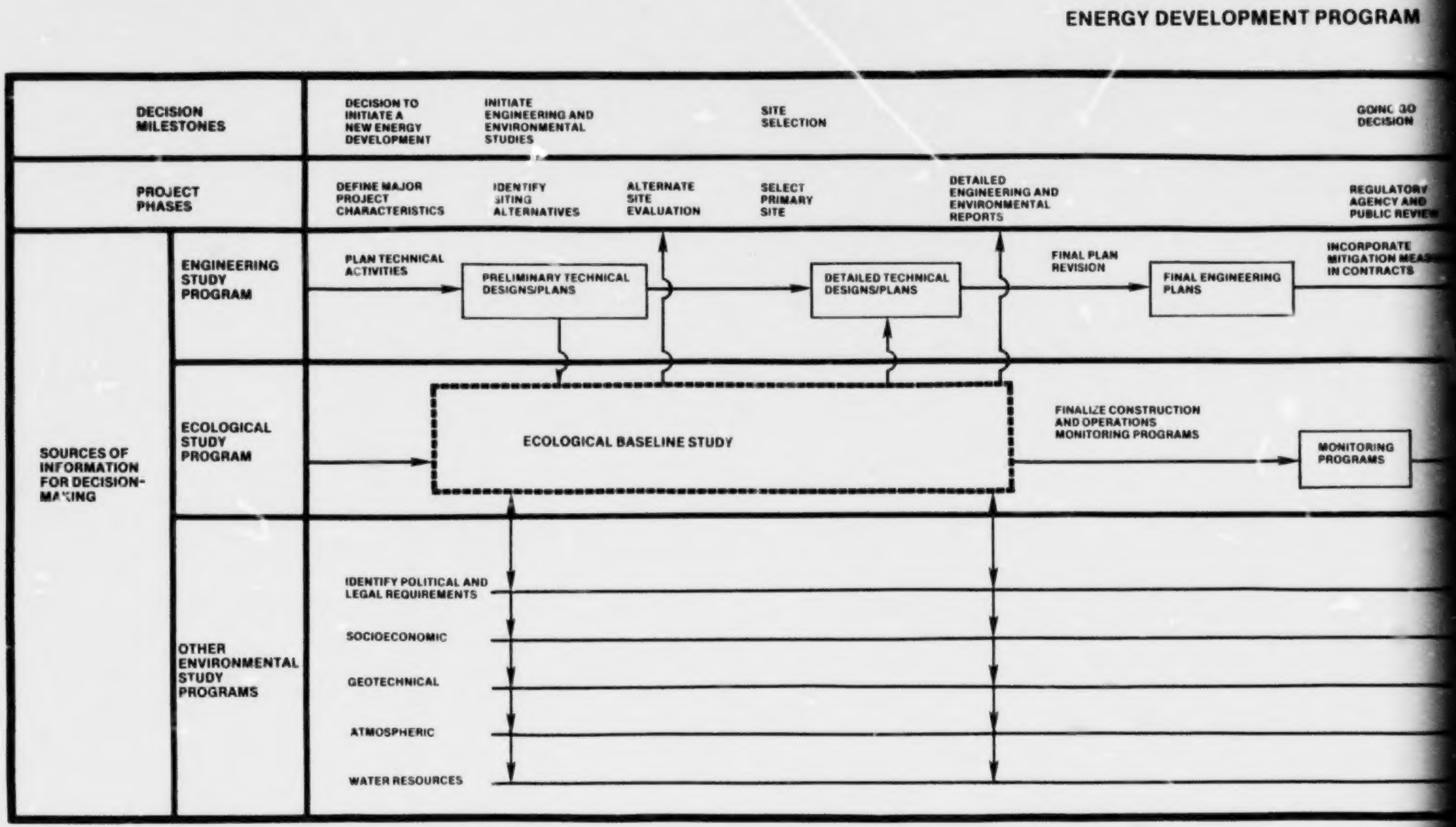
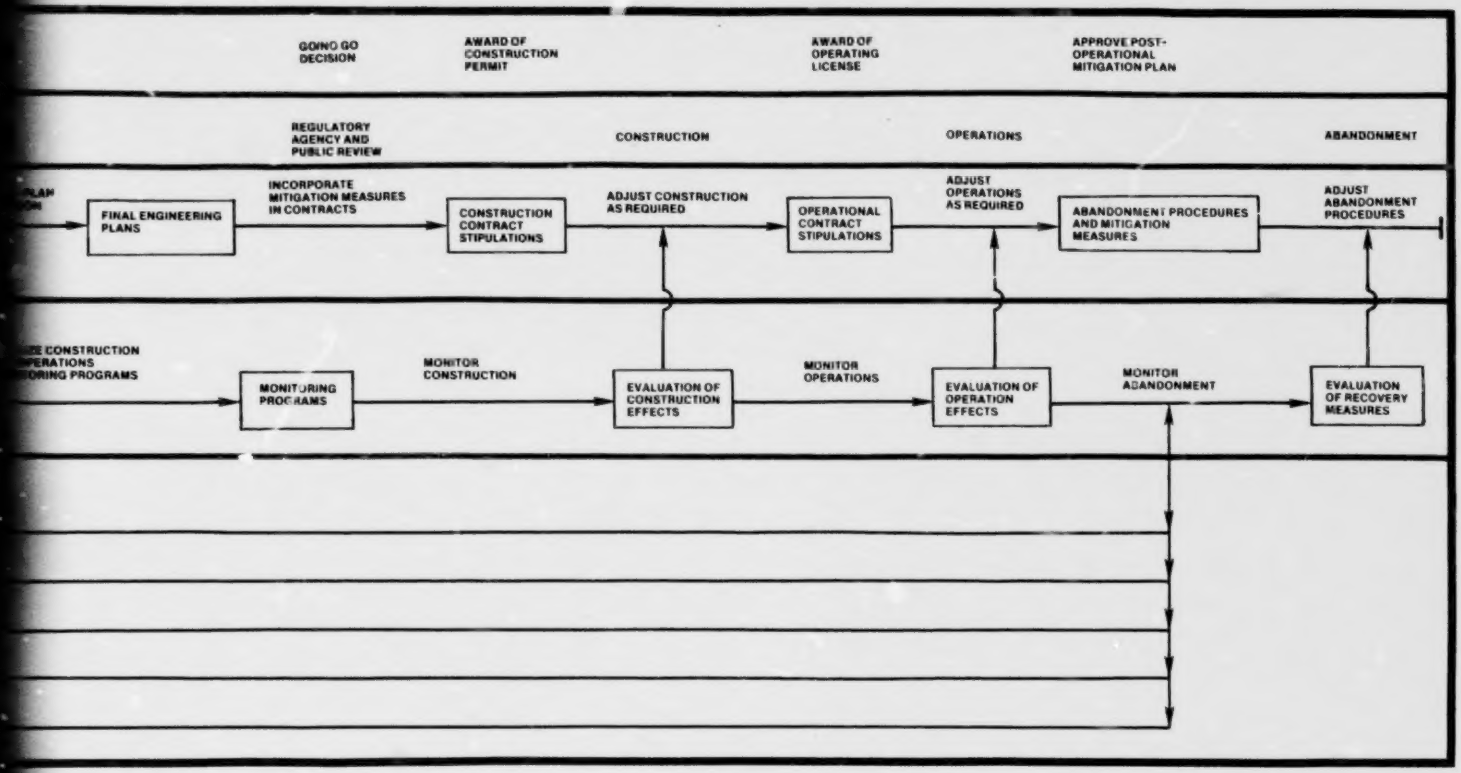

ENERGY DEVELOPMENT PROGRAM
DECISION MILESTONES
DECISION TO INITIATE A NEW ENERGY DEVELOPMENT
INITIATE ENGINEERING AND ENVIRONMENTAL STUDIES
SITE SELECTION
GOING GO DECISION
PROJECT PHASES
DEFINE MAJOR PROJECT CHARACTERISTICS
IDENTIFY SITING ALTERNATIVES
ALTERNATE SITE EVALUATION
SELECT PRIMARY SITE
DETAILED ENGINEERING AND ENVIRONMENTAL REPORTS
REGULATORY AGENCY AND PUBLIC REVIEW
SOURCES OF INFORMATION FOR DECISION-MAKING
ENGINEERING STUDY PROGRAM
PLAN TECHNICAL ACTIVITIES
PRELIMINARY TECHNICAL DESIGNS/PLANS
DETAILED TECHNICAL DESIGNS/PLANS
FINAL PLAN REVISION
FINAL ENGINEERING PLANS
INCORPORATE MITIGATION MEAS
IN CONTRACTS
ECOLOGICAL STUDY PROGRAM
ECOLOGICAL BASELINE STUDY
FINALIZE CONSTRUCTION AND OPERATIONS MONITORING PROGRAMS
MONITORING PROGRAMS
OTHER ENVIRONMENTAL STUDY PROGRAMS
IDENTIFY POLITICAL AND LEGAL REQUIREMENTS
SOCIOECONOMIC
GEOTECHNICAL
ATMOSPHERIC
WATER RESOURCES

Figure 1-1. The figure shows the ecological baseline study as an integral part
development program. The necessary interactions of study programs along a

ERGY DEVELOPMENT PROGRAM


GO/NO GO DECISION
AWARD OF CONSTRUCTION PERMIT
AWARD OF OPERATING LICENSE
APPROVE POST-OPERATIONAL MITIGATION PLAN
REGULATORY AGENCY AND PUBLIC REVIEW
CONSTRUCTION
OPERATIONS
ABANDONMENT
PLAN
FINAL ENGINEERING PLANS
INCORPORATE MITIGATION MEASURES IN CONTRACTS
CONSTRUCTION CONTRACT STIPULATIONS
ADJUST CONSTRUCTION AS REQUIRED
OPERATIONAL CONTRACT STIPULATIONS
ADJUST OPERATIONS AS REQUIRED
ABANDONMENT PROCEDURES AND MITIGATION MEASURES
ADJUST ABANDONMENT PROCEDURES
ZE CONSTRUCTION
PERATIONS
ORING PROGRAMS
MONITORING PROGRAMS
MONITOR CONSTRUCTION
EVALUATION OF CONSTRUCTION EFFECTS
MONITOR OPERATIONS
EVALUATION OF OPERATION EFFECTS
MONITOR ABANDONMENT
EVALUATION OF RECOVERY MEASURES

tudy as an integral part of the information gathering process for an energy
f study programs along a generalized project timeline are illustrated.

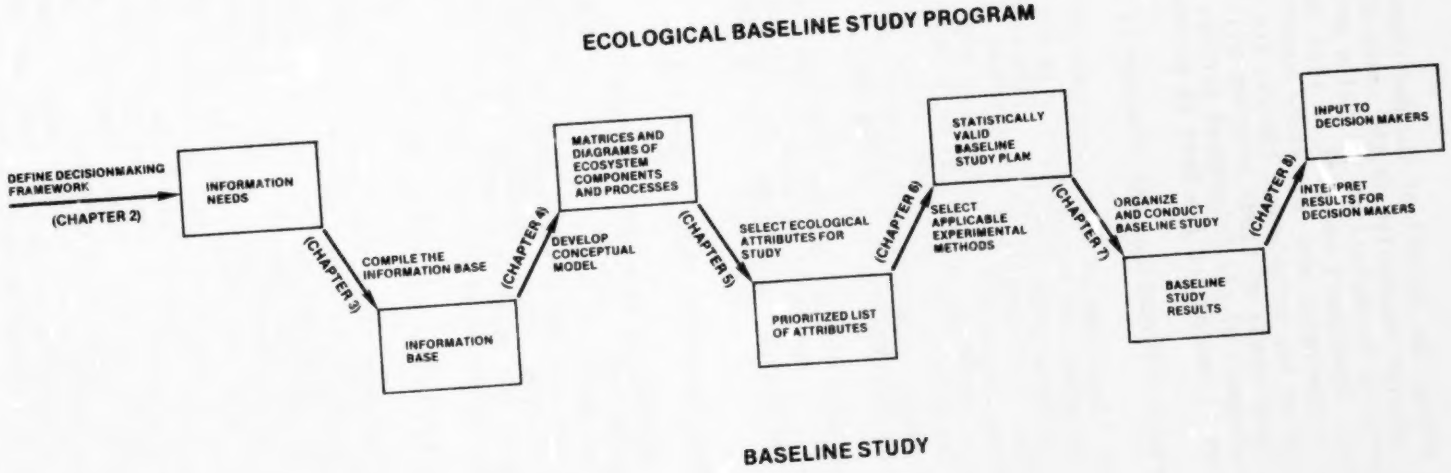

ECOLOGICAL BASELINE STUDY PROGRAM
DEFINE DECISIONMAKING FRAMEWORK
(CHAPTER 2)
INFORMATION NEEDS
(CHAPTER 3)
COMPILE THE INFORMATION BASE
INFORMATION BASE
(CHAPTER 4)
DEVELOP CONCEPTUAL MODEL
MATRICES AND DIAGRAMS OF ECOSYSTEM COMPONENTS AND PROCESSES
(CHAPTER 5)
SELECT ECOLOGICAL ATTRIBUTES FOR STUDY
PRIORITIZED LIST OF ATTRIBUTES
(CHAPTER 6)
SELECT APPLICABLE EXPERIMENTAL METHODS
STATISTICALLY VALID BASELINE STUDY PLAN
(CHAPTER 7)
ORGANIZE AND CONDUCT BASELINE STUDY
BASELINE STUDY RESULTS
(CHAPTER 8)
INTERPRET RESULTS FOR DECISION MAKERS
INPUT TO DECISION MAKERS
BASELINE STUDY

Figure 1-2. Major steps in the recommended approach to an ecological baseline study showing the relationship to the manual chapters.

It is only within the context of the decisionmaking framework that an ecological study program responsive to the needs of the decision process can be defined. A point to be emphasized is that a process of open planning is the key to success. Developers who want to keep their project under wraps until it is cast in concrete, and regulatory agencies who do not wish to give away their position on key development issues, are not operating in the public interest. The effectiveness of study programs will be in direct proportion to the degree of involvement of all interested parties in the early identification of what information is needed and how best to go about getting it.

Step #2 - Compile Information Base (Chapter 3)

The study itself begins with compiling and organizing a base of existing information about the proposed activity and how it relates to the socioenvironmental systems under scrutiny. This compilation will occur from two principal sources: (1) details of the planned development activities and possible environmental perturbations associated with each and (2) the best available information about the biological environment within which the activities will occur. The purpose of this compilation is to identify which of the stated information needs (objectives) is already met by existing information and which require new information to fill the gaps.

On the basis of information compiled from the literature, local experts, and site surveys, this is the point at which to evaluate siting alternatives. The information for each site needs to be organized to permit easy comparison between sites.

Step #3 - Develop Conceptual Model (Chapter 4)

Once the information base has been compiled, it is necessary to organize the information into a conceptual model of the ecosystems within the area of interest. The conceptual model itself is a set of graphics and documentary narratives that reflect the investigators' perception of the ecosystem, or ecosystems, being studied. This conceptual model is later used in selecting what will be measured in the baseline program. It is also used, after completion of the baseline study, in the assessment of impacts.

Step #4 - Select Ecological Attributes for Study (Chapter 5)

Once the above-named steps have been completed, we have a firm basis for proceeding with the really difficult job of choosing what ought to be measured in the field or laboratory during the field portion of the baseline study. What ought to be measured depends on what is important. "Importance" is based on four primary considerations. First, importance may be determined by the socioeconomic or legal requirements of the decisionmaking framework. Second, importance may be a function of the position of a component, process, or attribute in the structure and function of the ecosystem. We use the conceptual model to determine which of the many ecosystem components and processes are critical to the system. Third, importance can be determined by the expected impacts of the proposed development. If a component is apt to be impacted, it is a likely candidate for further study. Fourth, importance is modified by the extent of existing knowledge: Does our information base already contain sufficient information about a particular component or process?

Step #5 - Select Applicable Experimental Methods (Chapter 6)

Once ecosystem components, processes, and attributes of interest in the decisionmaking framework are identified, it is necessary to choose methods for measuring appropriate parameters. Methods selection is tempered by the limitations of the state of the art, which include considerations of accuracy, efficiency, cost-effectiveness, and the amenability of various methods to statistical analysis. Stepwise procedures for applying these important constraints to the final design of ecological baseline studies are too extensive to be included in this manual. However, major effort has been expended so that (1) where appropriate sampling methods do exist, advice is provided which will enable the manual user to select the best available methods for his particular situation, or (2) where appropriate sampling methods do not exist, promising avenues are suggested for experimental innovation and research wherein appropriate methods might be developed. In either case the objective is to help the user design an ecological baseline study that meets the needs of the decisionmakers by applying the best available investigative methods.

Step #6 - Organize and Conduct the Field Portion of the Baseline Study (Chapter 7)

After planning is complete and field methods are selected, the next step is to conduct the field and/or laboratory portions of the baseline study. This step deals with gathering ecological data and information needed by decisionmakers but which is not available from the existing information base. The field program is essentially a subproject of the entire baseline study; and as such, it will be performed by a project team. The chapter covers how to initiate the field project, how to control it and maintain ongoing evaluation of it, and how to terminate it. The discussion briefly summarizes the project manager's role in relation to the team and to technical and budgetary considerations of the field project.

Step #7 - Interpret Results for Decisionmakers (Chapter 8)

The results of an ecological baseline study should describe the existing ecological conditions and trends in the potentially affected region, providing a reference baseline from which environmental scientists can:

1. Predict the effects of the proposed action and recommend alternatives.

2. Define appropriate mitigation measures.

3. Design future programs to monitor the accuracy of predictions and the effectiveness of mitigation.

The implications of this are very clear. Basically such a study should take into account the fundamental structure, function, and interrelationships of an environmental system in such a way as to predict, within reason and the state of the art, the effects of a proposed action on that system. This implies gathering data and other information about that system and organizing, distilling, and integrating the facts in such a way that the decisionmakers and others influencing the decision process can understand the environmental ramifications of the proposed action.

1.3.3 Reference Materials

Because of the anticipated broad audience that will be using this document and the commensurate diversity of backgrounds, reference materials providing further explanation have been placed in three appendices.

The first, Appendix A, is a standard Literature Cited section that contains a list of references cited in the text. Appendix B provides a Glossary of terms used in this manual, plus many more that are common to the field of ecology and to energy development activities. Appendix C is an Annotated Bibliography of superior references that amplify the material in the text.

These reference materials should prove useful in establishing a common vocabulary and starting point for conducting successful ecological baseline studies.

2.0 DEFINE THE DECISIONMAKING FRAMEWORK

2.1 INTRODUCTION AND OVERVIEW

Decisionmaking is the process of reaching binding judgments about what should or should not be done in an energy-development program. The decisionmaking framework comprises all the considerations associated with making decisions. This framework is not an easily visualized structure; rather it is a loosely defined conglomeration of the development plans, the natural resources affected by the development, the planners, the governmental agencies that grant permits, baseline investigators, laws and their various interpretations, and a variety of other entities, all of which may significantly affect decisionmaking.

Usually, the bigger the project, the more people are concerned about it, and the more complex the decisionmaking framework will be. However, not all elements of the decisionmaking framework for the energy-development program affect the ecological baseline study. Therefore, the first task in any baseline program is to determine which components of the decisionmaking framework are pertinent to the baseline study.

The following elements influence the design and conduct of nearly all ecological baseline studies:

1. Major characteristics of the proposed development.

2. Sociological requirements.

3. Economic requirements.

4. Legal requirements.

5. Major decisions about the proposed development.

6. Persons responsible for making decisions.

7. Other persons who are interested in or concerned about the development.

8. The information needs of persons in 6 and 7 above.

Overall, our task is to prepare a written statement of the purpose, goals, and objectives for the baseline study. This statement must address the information needs of the decisionmaking process. The specific objectives link the decision framework with the baseline study. Getting to this statement involves four major steps:

1. Identify major characteristics of the proposed development.
2. Define the socioenvironmental system(s) of interest in terms of (a) socioeconomic requirements, (b) legal requirements, (c) persons involved in decisionmaking, and (d) spatial and temporal boundaries.
3. Document the information needs of the decisionmaking process.
4. State the purpose, goals, and objectives for the ecological baseline study.

Satisfying the above four requirements can be frustrating. The rules in decisionmaking change, as do the names and personalities of those who apply them. It is often difficult to determine what judgments need to be made and who will make them. Nonetheless, project developers, engineers, socioenvironmental investigators, and government-agency personnel all need to know how decisions will be made. The thoroughness with which this group defines the decisionmaking framework greatly influences how well the development program stays on schedule and if it stays within the bounds of economic and environmental acceptability. In general, the costs of even minor delays resulting from a failure to properly define information needs will far exceed the costs of efforts to define the decisionmaking framework.

A baseline study depends on (1) individuals, corporations, and agencies involved in the decisionmaking process; (2) their regulatory, legal, and social responsibilities to that process; and (3) the questions that must be answered before they can properly discharge those responsibilities. The study must answer these questions. Therefore, organizations and individuals making the decisions should be heavily involved in defining the objectives of such studies, and they should assist in designing study programs to achieve those objectives. Further, the decisionmakers must act together to insure that an integrated program is designed to answer all important questions.

Certain groups and agencies will have specific responsibility for, or interest in, ecological problems associated with the proposed energy development. For this reason, developers should arrange special meetings early in the program between their project planners, ecological experts from the concerned groups, and the developer's ecological experts. At those meetings, project planners will identify what they want to do; ecological experts from concerned groups and agencies will identify the information they need to allay their concerns; and the developer's experts will identify how much and what kinds of information can be reasonably obtained within constraints of time, dollars, and the state of the art.

The key to success in this step is open planning. In essence this is simply a commitment on the part of the developer, the government-agency personnel, and all other actors in the decision process to mutually communicate their plans and concerns throughout the energy-development program, instead of only at the time when major decisions are being made. Remember the following:

- The developer is responsible for consulting with decisionmakers; the developer who tries to keep the project "secret" until the final reports are ready may learn a hard lesson.

- Decisionmaking agencies are responsible for providing accurate information on their interpretation of the laws affecting the development. In order to maximize input to final decisions, these agencies must contribute their input as early as possible, expressing concerns before a project passes a point of no return on a particular question.

- Ecological, socioeconomic, legal, and other investigators have responsibility for communicating with each other. One discipline often requires data from another; and this need should be addressed early by all parties.

- Finally, environmental and conservation groups bear a responsibility for communicating their concerns throughout the development program. Differences of opinion will be present in every energy-development program; cooperation between the various concerned groups will increase the chances of the development proceeding in a manner acceptable to all.

2.2 IDENTIFY MAJOR CHARACTERISTICS OF THE PROPOSED ENERGY DEVELOPMENT

First, from the preliminary plans of the developer, determine the physical size of the project, its time frame, and the geographic and political region affected by the project.

2.2.1 Determine Spatial Characteristics and Major Activities

The size of a project depends on its major activities and the space it will use. These two factors interact so closely that they are discussed together here.

2.2.1.1 Major Activities. You must understand how the project will function and what the major activities will be. If development plans are not well advanced, it is useful to treat the project as a "black box." Concentrate on input to and output from the site and on storage of materials. Details of extraction and processing can be left to the time when more detailed engineering plans become available.

Inputs will include:

1. Raw materials, methods of transportation, transportation routes, and volumes or tonnages involved.

2. Fluctuations in the total number of workers through the duration of the project, in daily shifts, or in concentrated arrivals on site. It is also important to know the number of family units likely to accompany the workers as a crude measure of impacts on local resources.

Outputs will include:

1. Products, their means and avenues of transport from the site and their amounts.

2. Waste materials, their rates of production, and methods of disposal.

Where the local environment is expected to receive outputs (e.g., gaseous, effluent, or particulate emissions), the volumes, rates of discharge, and expected dispersion into the environment must be forecast as accurately as possible.

Figure 2-1 illustrates a "black-box" approach to portraying inputs and outputs from a project development. This type of diagram is most useful when details of the development have not been well developed. The example situation is a major coal-fired power plant.

When details of the development are more fully developed, the black box can be filled in with descriptions of facilities required for the development and better estimates can be made of input to and output from the site. Table 2-1 adds this detail to the black box of Figure 2-1.

2.2.1.2 Zone of Influence (Spatial Characteristics). Define the project zone of influence. This is usefully broken down into an area of direct disturbance, usually enclosed within the legal site boundaries, and an area of indirect influence encompassing all areas potentially exposed to gaseous, liquid, particulate, or thermal pollution, or to changes in the patterns of natural-resource utilization by animal or human populations. As a minimum, obtain from the developer:

1. A plot plan showing the spatial arrangement and relative sizes of project facilities within site boundaries.

2. Estimates from literature or from experts of the expected distribution and concentration of indirect influences.

Figures 2-2 and 2-3 present example plot plans that would be required for a surface coal mine.

2.2.2 Determine Time Dimensions

Also very important are the time dimensions of the project. Figure 1-1 emphasized the necessity for integrating the technological and environmental study programs so that when a decision milestone is reached, the information needed for a wise decision is available. Therefore, find out not only the total time frame for the entire development program, but also the time frames for major phases of the project. These might include starting and ending times of construction, various operational phases, abandonment activities, reclamation activities, etc. Figure 2-4 provides an example of these time dimensions for an oil shale development in western Colorado.

2.2.3 Identify a Geographic/Political Region for the Development

Because regulations and environmental concerns differ so widely from one geographic area to another, it is impossible to define a decision framework without reference to a specific geographic location. The geographic/political

Table 2-1. Example summary of major activities in an energy development. This example assumes that preliminary engineering plans have been completed. Adapted from U.S. Department of Interior, 1971 and 19[illegible].

Example Situation: 1500 MW Coal-fired Power Plant with Cooling Towers or a River				
A. Major Activities	B. Facilities Required by Development	C. Input to Site	D. Outputs from Site	E. Zones of Influence
1. Construct facilities 2. Operate facilities 3. Generate power 4. Dispose of wastes 5. Supply fuel 6. Supply water 7. Transmit power	1. Temporary housing for construction force 2. Permanent housing for employees 3. Office facilities 4. Parking 5. Generating Plant (236' high x 710' long x 305' wide • boilers (206' high x 561' wide x 49' deep) • turbines (131' long) • cooling towers (342' long x 68' wide x 63' high) • stacks (500' high) • sulfur removal equipment • electrostatic precipitators 6. Coal-storage area 7. Coal processors & conveyors 8. Seven-mile railroad spur 9. Forty-two mile water pipeline 10. Eighty-acre surge pond 11. Ash-disposal areas bottom, fly, scrubber (together or separate) 12. Three 345-kv transmission lines, totaling 750 linear miles 13. Three 345-kv substations 14. Gravel pit during construction phase 15. Waste disposal facilities • sewage treatment plants • exchange resin residue 16. Intake structure 17. Discharge structures 18. Coal benification facilities	1. Construction materials 2. Approximately 2,000 employees during peak. Approximately 20 employees during operation 3. Coal @ 750 tons/hour 4. Water @ 29,200 acre feet per year	1. Fugitive dust from construction & coal processing activities 2. Ash (to be buried on site) 3. Trace elements (F, Pb, Hg, Se) 4. SO_2 (max 7840 lb/hour; min 3640 lb/hr) 5. NO_x (3900 lb/hr) 6. Particulates (max 325 lb/hr, min 197 lb/hr) 7. CO (75 lb/hr) 8. CO_2 (Ave. 1,060,000 lb/hr) 9. H_2O (max. 317,000 lb/hr; min. 251,000 lb/hr) 10. Blowdown residue 11. Electricity (1500 mw) 12. Salt drift from cooling towers 13. Fog and ice 14. Chlorine, phosphates and other anti-corrosion and antifouling chemicals 15. Blowdown (with cooling tower) • increase in TDS to environment • thermal component 16. Silt and sediment to aquatic system generated during construction of intake structure 17. Noise from operation of turbines, coal processors and conveyors 18. Storm water runoff from site • coal pile runoff • bottom, fly, and scrubber ash runoff 19. Discharges from ash ponds - most plants use slurry and in most areas evaporation is not sufficient to remove 20. Waste disposal discharges • sewage treatment - BOD, nitrates, phosphates • boiler makeup water treatment - exchange resin wastes	1. 500-acre site 2. Area of gravel pit 3. Right of way for railroad, access road, transmission lines, and pipeline 4. Downstream areas affected by removal of H_2O from river 5. Downwind areas, air dispersion models indicate maximum concentrations of gaseous and particulate emissions will occur between 1 and 5 miles downwind. 6. Areas of dam and/or surge pond construction (not necessarily on site) 7. Area of intake structure • impingement • entrainment • continued flow alteration 8. Downstream of discharge structure(s) • sewage wastes • bottom, fly and scrubber wastes • runoff wastes (over whole site) 9. Area between facilities and housing for construction and/or operation crew - traffic noise 10. Area around (esp. downwind) of cooling tower - i.e., fogging, salt drift, etc. 11. Groundwater table and/or groundwater quality of area

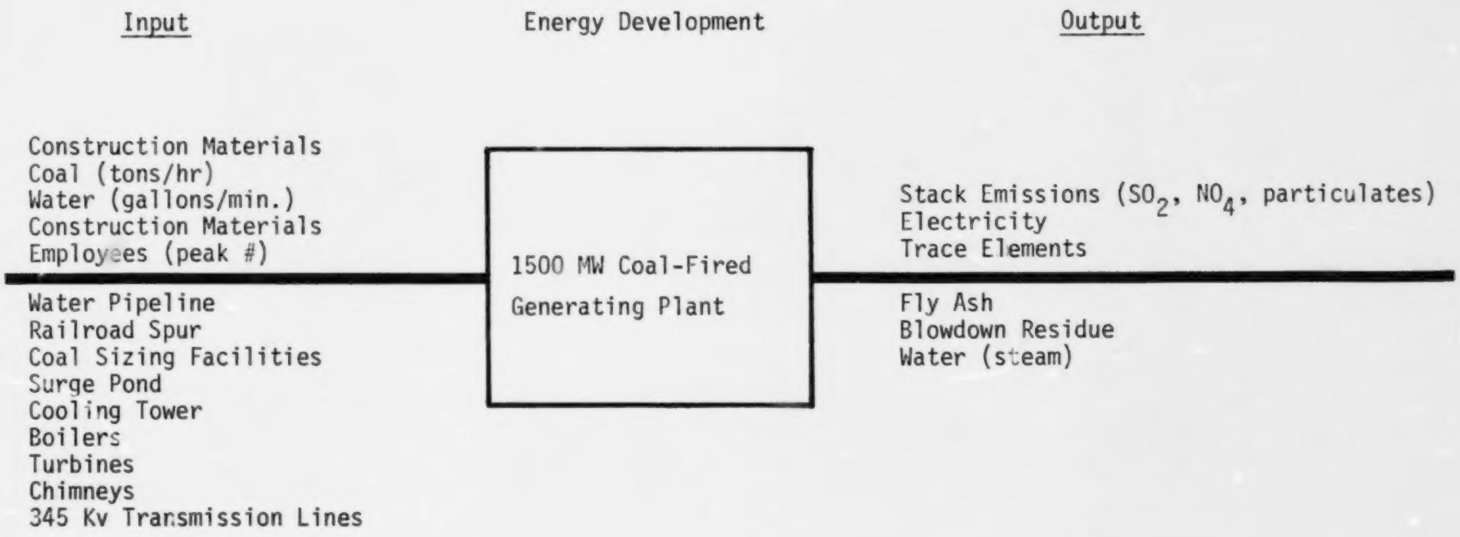

Input
Energy Development
Output
Construction Materials
Coal (tons/hr)
Water (gallons/min.)
Construction Materials
Employees (peak #)
Water Pipeline
Railroad Spur
Coal Sizing Facilities
Surge Pond
Cooling Tower
Boilers
Turbines
Chimneys
345 Kv Transmission Lines
1500 MW Coal-Fired
Generating Plant
Stack Emissions (SO_2, NO_4, particulates)
Electricity
Trace Elements
Fly Ash
Blowdown Residue
Water (steam)

Figure 2-1. An example of a simple "black box" diagram of an energy development. The example situation is a large coal-fired power plant. This type of diagram can be useful for defining major project characteristics at a gross level of resolution, prior to development of engineering plans.

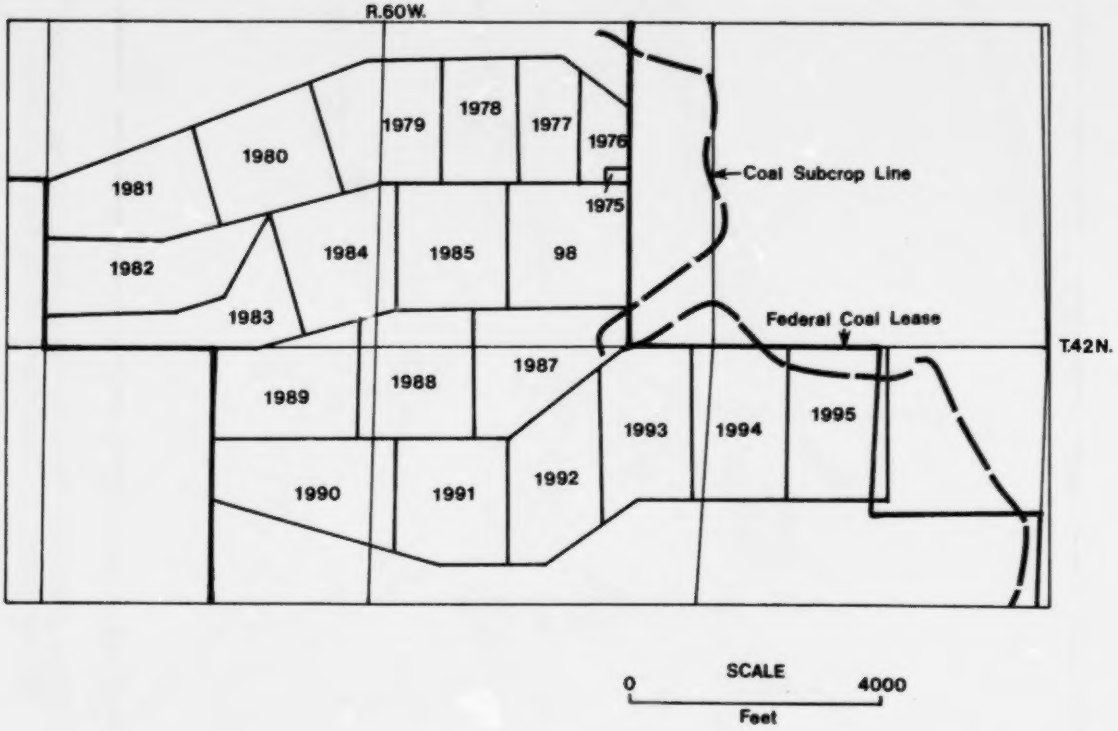
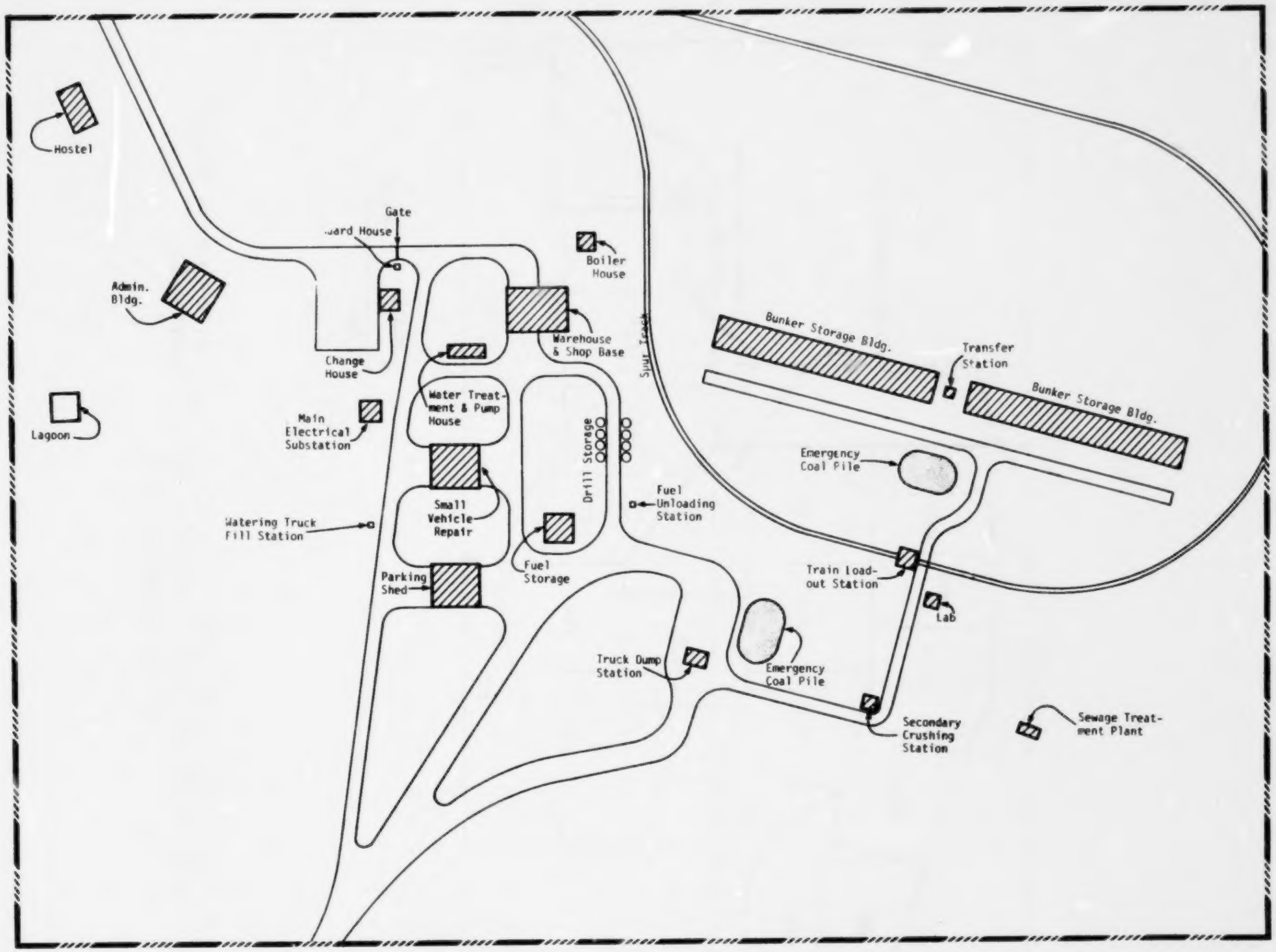

R.60W.
1979
1978
1977
1976
1980
1981
1975
Coal Subcrop Line
1982
1984
1985
98
1983
Federal Coal Lease
T.42N.
1987
1988
1989
1993
1994
1995
1990
1991
1992
SCALE
0
4000
Feet

Figure 2-2. An example plot plan for a surface coal mine showing the areas to be mined per year. Adapted from U.S. Department of Agriculture, 1974.



Hostel
Admin. Bldg.
Lagoon
Gate
uard House
Change House
Main Electrical Substation
Watering Truck Fill Station
Boiler House
Warehouse & Shop Base
Water Treatment & Pump House
Small Vehicle Repair
Parking Shed
Fuel Storage
Drill Storage
Fuel Unloading Station
Spur Track
Bunker Storage Bldg.
Transfer Station
Bunker Storage Bldg.
Emergency Coal Pile
Train Load-out Station
Lab
Truck Dump Station
Emergency Coal Pile
Secondary Crushing Station
Sewage Treatment Plant

Figure 2-3. Example plot plan for a surface mine, showing surface facilities. Adapted from U.S. Department of Agriculture 1974.

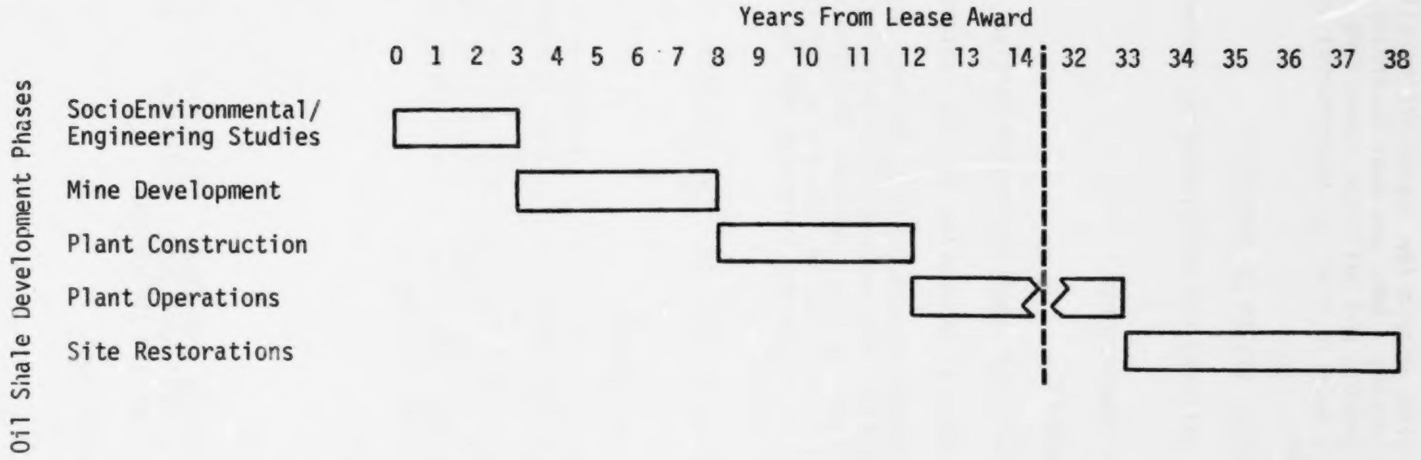


Figure 2-4. Example of time dimensions for an energy development program. The example situation is an oil shale development in western Colorado. Adapted from C-b Shale Oil Project 1977.

region and specific alternate sites within the region are usually already defined at this point in the planning. Now, you must determine the city, county, state, and federal geographic and political boundaries that apply to the sites. These include lands held in trust by governmental agencies, such as parks, forest preserves, etc.

2.3 DEFINE THE SOCIOENVIRONMENTAL SYSTEM OF INTEREST

The second major step in defining the decisionmaking framework involves four sub-steps:

1. Review socioeconomic requirements.

2. Review legal requirements.

3. Identify decisionmakers and other interested parties.

4. Select spatial and temporal boundaries for the system(s).

Use the legal and socioeconomic requirements as a first-pass filter, or screen, for determining the initial requirements for the ecological baseline study. Identify individual persons as decisionmakers and know who you are working with. Often it is not so much the institution or the letter of the law as it is the personalities of people who interpret the law that determine the outcome of the decisionmaking process.

Set boundaries on the system in order to focus attention on specific areas and times of concern.

2.3.1 Review Socioeconomic Requirements

Establish contact with socioeconomic experts involved in or familiar with the program. These include socioeconomic investigators retained by the developer as well as others (e.g., local, city, and county planners). Ask these sociologists and economists to identify from their perspectives the resources that should be studied by biologists and the kinds of information needed about these resources to satisfy the laws governing socioeconomic considerations. Generally resources are considered if they are:

1. Economically valuable.

2. Unique.

3. Aesthetically valuable.

2.3.1.1 Economically Valuable Resources. Any resource that provides revenue to the development area will need to be evaluated if it is potentially affected by development. Consider the following:

1) Agriculturally valuable land.

2) Timber stands.

3) Wildlife populations and habitats.

4) Sport-fish populations and habitats.

5) Important recreational areas.

The decision process demands specific, quantitative information when these resources are concerned. The kinds of questions that may require biological investigations include:

1) What resources are present?

2) What is the current size, extent, or condition of the resource (e.g., how much timber, how many deer, how productive is the rangeland, etc.)?

3) How can we detect the size, extent, or condition?

4) How will the development affect the future size, extent, or condition of the resource?

5) What mitigation measures can be employed to reduce resource loss?

6) What monitoring techniques can be used to evaluate mitigation success?

Much of the necessary preliminary information can be obtained through literature review. Where field data are needed on specific resources identified here, Chapter 6 recommends methods for collecting those data.

2.3.1.2 Unique Resources. This category includes resources that may be unique for a number of reasons. In general, species, habitats, or communities that are uncommon in the general surrounding area are considered unique. Examples include the presence of a spring in a desert, hardwood draw in a prairie, an undisturbed portion of short-grass prairie amidst a large tract of grazing land, or the presence of a relatively rare species within a specific area. Threatened or endangered species are considered unique resources; these are discussed separately in Section 2.3.2.3.

To determine whether a resource is unique, consider the amount of a resource within a region relative to what will likely be lost due to development. If a project is going to affect a substantial portion of the resource, this loss should be considered important. The biological investigator will often be asked to use his expertise to determine the extent of the resource, predict the effect of development on the resource, and make preliminary recommendations for mitigation methods to reduce or compensate for resource losses.

2.3.1.3 Aesthetically Valuable Resources. Certain areas or species may not be important economic resources or particularly unique resources, but may possess a high degree of aesthetic appeal. Examples are a particularly scenic stretch of river, a wooded area favored by local birdwatchers, or a particularly scenic rock outcrop. Identifying aesthetically important resources and determining importance is wholly subjective and therefore is difficult and controversial. This must largely be done by others and communicated to the ecological investigators who can then use techniques discussed in Chapter 6 to evaluate ecological elements of the resource.

2.3.1.4 Summarize Socioeconomic Requirements. As a result of the above-described review process, summarize the important socioeconomic requirements, and include:

1. A list of important resources potentially affected by the development.

2. Maps showing locations of these resources or areas.

3. Information needs identified by sociologists and economists.

2.3.2 Review Legal Requirements

Legal requirements for baseline studies vary extremely, depending on the type of development, its size, and its location. Requirements may come from many sources including:

1. State and federal law.

2. State and federal regulators.

3. Requirements for obtaining permits.

4. Stipulations contained in land or mineral leases.

These requirements are often ill-defined and can be approached only on a case-by-case basis. This makes it hard to predict in advance exactly what may be required.

Begin by identifying state and federal agencies that may be involved. Ask the developer which agencies he feels should be contacted. Most developers will have had experience on previous projects and will have a fairly clear idea of what agencies have responsibility. Two useful books that can be consulted are the United States Government Manual, which is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20020, and the annual Conservation Directory published by the National Wildlife Federation, 1412 Sixteenth Street, NW, Washington, D.C. 20036. The former contains discussions on the responsibilities of all federal agencies. The latter contains similar discussions for both state and federal agencies.

Once agencies have been identified, contact them and ask which laws and regulations apply to the proposed development. Specifically ask government agencies for their official interpretations of the kinds of biological investigations expected or required according to state, federal, or other law. The following subsections outline major areas of concern.

2.3.2.1 Federal Requirements. Many federal laws may apply to an ecological baseline program. Probably the most important of these, because of its applicability to all major actions of federal agencies, is the National Environmental Policy Act of 1969, or NEPA. Because the majority of the energy resources in the West are on or under federal land, most of the developments will require preparation of an environmental statement as required by Section 102(2)(C) of

NEPA. At a minimum, investigations will be required to provide the ecological information necessary to prepare the proper environmental reports. (See Chapter 1 for a list of required report sections under NEPA.)

Various other federal laws contain provisions that affect the content and scope of a baseline study under certain circumstances. The Federal Water Pollution Control Act Amendments of 1972, the Clean Air Act, and the Surface Mining Control and Reclamation Act of 1977 are good examples. Certain procedures required to obtain a permit for a development may also require baseline data. Also, if a development involves leasing lands from federal agencies, studies may be called for in lease stipulations (e.g., leases for the prototype oil shale development in Colorado and Utah). For the most part, the agency chiefly responsible under NEPA will be able to direct biological investigators to other agencies that may require studies in the baseline program.

2.3.2.2 State Requirements. Requirements at the state level may be more or less complicated, more or less strict, than those at the national level. Many states have their own versions of NEPA as well as other laws that affect the development of energy resources. Many states also require permits for mining and other activities associated with energy development. As does the federal government, various state agencies have responsibility for maintaining the quality of various aspects of the environment within their state. These agencies should be contacted, depending on the characteristics of the specific development. Often their input to the baseline study design is required.

2.3.2.3 Threatened and Endangered Species. Although threatened and endangered plants and animals fall into both the legal and socioeconomic categories previously discussed, they are important enough to warrant special consideration. Their importance lies not so much in their roles as functional components of the ecosystem as it does in the value that societies here and around the world have placed on their survival. Such species have biological value in maintaining diversity within a community and, in the case of subspecies, within gene pools. The primary reason for their consideration in baseline studies, however, is that once lost, they cannot be replaced. Endangered and threatened species are protected by both public opinion and state and federal legislation.

Endangered species are those in danger of extinction throughout all, or a significant portion, of their range; threatened species are those likely to become endangered within the foreseeable future (Schwarz et al. 1976). Technically, however, species are neither threatened nor endangered unless they have been designated as such by the Secretary of the Interior and listed in the Federal Register (Volume 42, No. 135).

Several states also have their own lists and regulations either more or less comprehensive than the federal list. Consult fish and game departments within those states when appropriate.

The major federal legislation dealing with threatened and endangered species is the Endangered Species Act of 1973 (87 Stat. 887, 16 U.S.C. 1531-43) and the regulations that have been written for its implementation (50 CFR 17). These regulations prohibit the "taking" of any endangered or threatened species within the United States or its territorial waters. The definition of "take" in 50 CFR 17 includes killing, harming, and harrassing. Definitions of "harm" and "harrass" should be taken into consideration when energy developments are planned.

Harrass means "an intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding, or sheltering." (50 CFR 17.3)

Harm means "an act or omission which actually injures or kills wildlife, including acts which annoy it to such an extent as to significantly disrupt essential behavioral patterns, which include, but are not limited to, breeding, feeding, or sheltering; significant environmental modification or degradation which has such effects is included within the meaning of harm." (50 CFR 17.3)

Obviously, the presence of a threatened or endangered species within a development area has important ramifications for the entire development process, from site selection, through plant design and operation, to impact mitigation. When such species are potentially present, you will need to work carefully with engineers and decisionmakers, especially the U.S. Fish and Wildlife Service, to assure that baseline study plans are designed to gather the information base necessary to prevent the taking of any threatened or endangered species.

2.3.2.4 List Legal Requirements. Summarize the above review with a list of the legal requirements important to the ecological baseline study. Include in the summary information on:

1. Federal and state agencies with decisionmaking or review responsibilities.
2. Permits requiring ecological information.
3. Applicable state and federal laws and their specific requirements.
4. Official interpretations of state and federal laws.
5. Information needs identified by state and federal agency representatives.
6. Specific requirements of reports that must be produced.

2.3.3 Identify Decisionmakers and Other Interested Parties

It is not sufficient just to know what the legal and socioeconomic requirements of the baseline study are; you must also know who will apply the requirements to the project and what interpretations they are likely to make. You have already made contacts with representatives of governmental organizations. Now seek out and contact the actual decisionmakers who enforce the laws and regulations. In identifying decisionmakers, remember this: where the responsibility for a decision belongs to a whole group or agency, the group leader or agency administrator is probably the individual who actually signs the decision, but he will likely be acting upon the recommendation of one or more of his staff members. It is to the staff members you must go to find out what information is required.

The discussion given above generally applies to those with legal authority over, or responsibility for, the energy development in question. Their information needs must be the first priority for the baseline-study program. However, there are also interagency agreements that require the agency making the decisions to consider certain concerns of other agencies. Often, the project must also be reviewed by private citizens and citizens' groups. Such groups can significantly influence the decision process. Therefore it is important to include their views within the decision framework.

Prepare a list of decisionmakers and other involved parties and summarize each person's potential involvement in the decisionmaking process. The list will serve as a "cast of characters" for the energy development.

2.3.4 Select Boundaries for the Study

Identify spatial and temporal boundaries for the baseline study that are consistent with the legal and socioeconomic requirements defined above. Consider the development site and the ecosystem(s) on it (1) within the larger context of contiguous lands and, (2) within the context of the development time horizon. Refer to the description of the development obtained earlier (Section 2.2).

2.3.4.1 Spatial Definition. Check the plans and maps of the development site against other, more detailed maps of the region, and consider questions of the following type:

1. How is the area under development related to the surrounding area?

2. What sorts of flows connect the development area with the surrounding area (e.g., water movement, traffic patterns, animal migration routes, prevailing wind direction, etc.)?

3. Where can I draw a boundary on the larger area to be fairly certain that the proposed development will not seriously affect lands beyond that boundary?

4. Where can I put the boundaries to achieve a balance between too much detail and not enough?

At this point it is better to be too comprehensive rather than too narrow in scope. You can reconsider these boundaries later if necessary. Define boundaries using the following steps:

1. Identify the geographical boundaries for the area.

2. Identify major topographical features.

3. Identify broad vegetational communities, major cultural regions (cities, etc.), and other distinct functional spatial units within the geographic boundaries.

4. Specify vertical boundaries of the area (e.g., how high above the highest structure and how low below the lowest root zone, soil horizon, or foundation, the vertical boundaries of the system(s) should be placed).

The output from these steps should include:

1. A set of maps containing geographical boundaries, topographical features, major vegetational communities, major cultural regions, and other functional spatial units within the geographic boundaries. (The maps should include the contiguous regions outside the geographical boundaries, and significant features of these regions.)
2. A description of, and rationale for, the vertical boundaries.

2.3.4.2 Temporal Definition. The schedule and plans for energy development contain not only a total time horizon, but also specific time frames for various phases of the development. You need to know both in order to plan a phased sampling program. If an operational phase of the development is not scheduled to begin for 5 or 10 years, it might not be necessary to study the site for the activity until later.

Based on this information, specify a time horizon and possibly establish a preliminary schedule for the ecological baseline study, documenting the rationale for your choice.

2.4 DOCUMENT THE INFORMATION NEEDS OF THE DECISIONMAKING PROCESS

Once the system of interest has been defined as above, and the various lists of socioeconomic concerns, legal requirements, and involved parties have been prepared, it is necessary to move from the decision milestones in the energy-development process to the specific information needs at each decision point.

2.4.1 Decision Milestones

Decision milestones are the major "hurdles" a developer must clear in the course of the energy-development program. Figure 1-1 illustrates decision milestones for a generalized energy-development program. Prepare a list of the decision milestones for the specific development project.

2.4.2 Define Information Needed

For each decision milestone determine the following:

1. What are the specific decision points under the decision milestone? Many decision milestones are really composed of several specific decision points. (For example, in awarding a construction permit there may actually be several permits required.)
2. What regulations apply to the decision point?
3. What agency or group is responsible for administering the regulations?
4. Who will make recommendations to the administrator?
5. What are the concerns expressed by those individuals?
6. What information is needed to address those concerns?

Table 2-2 presents an example format for displaying the above information. This format can easily be adapted to display the information needs of other parties who have a stake in the decision process, but who are not directly responsible for making the decision.

Table 2-3, 2-4 present examples of the use of Table 2-2. The decision milestone is the award of the construction permit for a hypothetical coal-fired power plant located in Wyoming. The decision points considered are the award of the construction permit by the Wyoming Industrial Siting Council and the award of a permit from the U.S. Army Corps of Engineers to discharge fill or dredge materials into waters. Tables 2-5 and 2-6 present examples of the use of an adapted version of Table 2-2 for displaying the information needs of other parties with a stake in the decisionmaking process.

Fill out as many forms as are needed to document the information needs at each decision point. These documented information needs form the backbone of the statement of purpose, goals, and objectives for the baseline study.

2.5 STATE THE PURPOSE, GOALS, AND OBJECTIVES FOR THE ECOLOGICAL BASELINE STUDY

Once you have documented the information needs of the decisionmaking process, you can focus the information-gathering efforts of the baseline study. This is done by translating the information needs into a statement of the purpose, goals, and objectives for the ecological study program.

2.5.1 Purpose

Ask the question, "What is the purpose of this particular study?". The answer should bear directly on how intensive the study will be. A statement of purpose for an ecological study program should tell, in broad terms, what the results will influence. Generally, ecological baseline studies should obtain the best possible ecological input for energy-development decisions.

The purpose of any study may be defined either qualitatively or quantitatively. For instance, one agency may simply require better qualitative information on the natural resources under its jurisdiction; under different circumstances, or under the jurisdiction of another agency, requirements might include verifiable, quantitative predictions about the likely effects of the project. To achieve the stated purpose, then, the study may range in intensity from a generalized resource inventory to a quantitative analysis that provides input to a computerized simulation model for predicting impacts prior to an energy development. The purpose or purposes of a baseline study must be defined by the decisionmakers in terms of the decision that must be reached. For example:

1. The purpose of a baseline study for a proposed power plant might be: To enable decisionmakers to select a best siting alternative on the basis of its having the least potential for biological damage.

2. The purpose of a baseline study for a small coal mine might be: To enable decisionmakers to evaluate the effectiveness of reclamation efforts through comparison of predevelopment and postreclamation conditions.

Table 2-2. Example format for documenting information needs at each decision point.

Decision Information Needs

Decision Milestone:

Specific Decision Point:

Regulations Applicable to Decision Point:

Agency or Group Responsible for Administering Regulations:

Individuals Who Will Make Recommendations:

Concerns Identified by Individuals:

Information Needed to Address Concern:

Table 2-3. Decision framework. Example use of suggested format for documenting information requirements on the legal obligations of a proposed energy development.

Decision Information Needs

Decision Milestone: Construction Permit

Specific Decision Point: Approval by Wyoming Industrial Siting Council

Regulations Applicable to Decision Point:

1. Wyoming Industrial Siting Council.
2. Rules and Regulations offered by Industrial Siting Council 9/9/75. Wyoming Statutes 35-502.75 through 35-502.94 and Wyoming Statutes 9-276.19 through 9-276.29.

Agency or Group Responsible for Administering Regulations:
Wyoming Industrial Siting Council

Individuals Who Will Make Recommendations:
Staff members in the Industrial Siting Administration: Engineer; Natural Resources Specialist; Sociologist; Attorney

Concerns Identified by Individuals:

1. Application must include rather detailed information required by Rules and Regulations.
2. Council Staff are especially concerned with the quantitative assessment of impacts caused by outputs from the project (e.g., NO_x, SO_2, particulates, trace elements).
3. Especially interested in migration routes and critical habitat for wildlife.
4. Require thorough assessment of environmental impacts of development.

Information Needed to Address Concern:

1. All information expressed in regulations.
2. Need to know current and predicted levels of NO_x, SO_2, particulates, trace elements. Also need to know threshold levels (where possible) for important species.
3. Need to relate vegetation characteristics to wildlife habitat needs. Need to survey current value of habitat prior to development. Need to gather information on migration routes.
4. Need to adequately identify development activities and associated perturbations. Must relate perturbations to various components of the development area, including social, economic, hydrologic, and ecologic.

Table 2-4. Decision framework. Example use of suggested format for documenting information requirements on the legal obligations of a proposed energy development.

Decision Information Needs

Decision Milestone: Construction Permit award

Specific Decision Point:
Award of Permit from U.S. Army Corps of Engineers to discharge fill or dredge materials to waters.

Regulations Applicable to Decision Point:
1. National Water Pollution Control Act Amendments of 1972, Section 404.
2. Regulations Federal Register 42: 138, part 323, July 1977.
3. National Environmental Policy Act of 1969.

Agency or Group Responsible for Administering Regulations:
U.S. Army Corps of Engineers

Individuals Who Will Make Recommendations:
District Chief Engineer

Concerns Identified by Individuals:
1. Concerned with the impacts of reduced flow below the Cutthroat Reservoir, especially impact on waterfowl, sandhill crane, and whooping crane. Also concerned with cumulative impacts downstream.
2. Concerned with prediction of rate of trace element emissions and possible effects on environment.
3. Concerned about possibility of thermal stratification in reservoir and potential effects on aquatic biota, especially fish.
4. Wants to make sure REA Impact Statement is adequate to cover Army Corps of Engineer actions.

Information Needed to Address Concern:
1. Need assessment of flows in downstream reaches. Need waterfowl and crane inventory along river. Need to address concern in terms of flow characteristics and population characteristics of these two components.
2. Need detailed chemical analysis of fuels, prediction of emission rates. Need quantitative definition of existing conditions.
3. Need study of stratification potential in proposed reservoir.
4. Requires additional and frequent consultation between REA and Corps.

Table 2-5. Decision framework. Example use of suggested format for documenting information requirements of other parties having a stake in the decisions.

Decision Information Needs

Decision Milestone: Construction Permit

Specific Decision Point: Application for Permit for Wyoming Industrial Siting Council.

Regulations Applicable to Decision Point:
Wyoming Statutes 35-502.75 to 35-502.94, 1975 Laws and Chapter 169;
Wyoming Statutes 9-276.19 to 9-276.24, 1975 Supplement.

Agency or Group Responsible for Administering Regulations:
Wyoming Fish and Game Department

Individuals Who Will Make Recommendations:
Various staff members

Concerns Identified by Individuals:

1. Concern over characteristics of downstream flow after dam and reservoir construction. If low flow situations will occur, what will be the impacts?
2. Would like to see the application discuss the value of the proposed reservoir as a fishery.
3. Concerned about any possible impacts on wildlife; would like to see quantitative assessment of wildlife impact; concerned about poaching by workers; would like to see planning for wildlife habitat improvement included in siting application.

Information Needed to Address Concern:

1. Project engineers and planners must specify conditions under which low flow will be induced, and quantify the extremes possible. Biological, socioeconomic, legal studies must gather data sufficient to predict impacts.
2. Description of reservoir water quality parameters must be provided. Useful to compare similar reservoirs in other areas. Habitat requirements of likely fishes to be stocked should be investigated.
3. Need quantitative information on wildlife. Need detailed engineering plans, soils information to plan mitigation, monitoring, and compensation.

Table 2-6. Decision framework. Example use of suggested format for documenting information requirements of other parties having a stake in the decisions.

Decision Information Needs

Decision Milestone: Go, No-Go

Specific Decision Point: Loan award from REA

Regulations Applicable to Decision Point:
1. National Environmental Policy act of 1969.
2. REA Bulletin 20-21: 320-21.

Agency or Group Responsible for Administering Regulations:
U.S. Forest Service

Individuals Who Will Make Recommendations:
Regional Office

Concerns Identified by Individuals:
1. Concerned about effects on wildlife, size of current and projected populations.
2. Mitigation of possible large effects on wildlife resulting from loss of habitat due to reservoir.
3. Concerned about effects of emissions on vegetation, especially Ponderosa Pine forests.

Information Needed to Address Concern:
1. Quantitative data on wildlife populations.
2. Characteristics of vegetation potentially surrounding the reservoir, suitability for wildlife habitat. Need to explore alternate management schemes.
3. Need information on existing damage to vegetation; air quality modeling to determine probable concentrations during plant operations.

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3. The purpose of a baseline study for a major oil shale development might be: To provide decisionmakers with quantitative estimates of the potential effects of the development on key ecological components of the ecosystem.

2.5.2 Goals

For each purpose, express goals in terms of (1) the kinds of information the study must provide in fulfilling the purpose and (2) the use to which the information will be put. Examples of possible goal statements under goal one above include:

1. To define the spatial limits of the geographic areas and ecological systems potentially affected by each alternative of the proposed activity as a basis for site selection.

2. To identify major ecological problems associated with each siting alternative (e.g., rare or threatened species, unique habitats, or limited but economically important natural resources) which could influence siting decision.

3. To obtain quantitative data on key components and processes within the environmental systems of the chosen area as a basis for predicting how they will be affected by development.

2.5.3 Objectives

For each goal develop a set of specific objectives (logical subdivisions of the goal) to serve as the foundation for the baseline study program. State each objective in terms of (1) information needed to satisfy the goal, (2) where and how the information will be obtained, (3) the time frame for obtaining it, and (4) how attainment of the objective will be measured (performance criteria). An example of an objective under goal (3) above would be: Obtain reasonable estimates of net primary forage production through one annual cycle, by using appropriate field techniques and replicate sampling to provide 90% confidence limits around estimates obtained. Table 2-7 presents a possible format for documenting the purpose, goals, and objectives.

If the ecological study program is designed to meet the objectives, it will also satisfy the goals and fulfill the purpose. Ideally, the project team will develop the statement of purpose, goals, and objectives in consultation with the other parties involved in the decision process, particularly the regulatory agencies. This approach may require considerable early negotiation between decisionmakers and developers. It will also serve to resolve most problems at the outset and to give all participants a role in defining the study program and thus a stake in its success.

Table 2-7. Suggested format for relating information needs identified in the decision framework to the goals and objectives of an ecological baseline study program.

Information Need Identified in Decision Framework:

Restatement of Need in the Form of Goals:

Information Needed to Satisfy Objective:

Information Source/How Obtained:

Information Time Frame:

Criteria for Measuring Information Adequacy:

3.0 COMPILE AND ORGANIZE EXISTING INFORMATION

3.1 INTRODUCTION AND OVERVIEW

Up to this point, we have identified the information needs based on the decisionmaking framework; the statements of purpose, goals, and objectives; and the boundaries and constraints of the socioenvironmental systems we will be studying (Chapter 2). These steps are really preliminaries to the actual ecological baseline study; they establish the necessary ground rules and guidelines for conducting the study.

The study itself begins with compiling and organizing a base of existing information about the proposed activity and how it relates to the socioenvironmental systems under scrutiny. Information already compiled from steps in Chapter 2 will generally be restricted to special-case considerations. We must now gather more information about both technological development and ecological factors.

Existing information will usually come from four principal sources:

1. Engineering designs and technical plans.
2. Local experts.
3. Publications.
4. Site reconnaissance.

This information can serve at least two purposes:

1. If a specific site has not yet been selected, the base of existing information can influence the major decision of choosing among alternate sites.
2. The information is used to develop a conceptual model to identify key ecosystem components, processes, and attributes for the field portion of the ecological baseline study.

Technological information about the project is probably the easiest to get. Very likely you will have already obtained and used the engineering plans as input to developing your information needs (Chapter 2). Now the plans are reviewed from a slightly different perspective (Section 3.2).

Ecological information about the proposed sites will be harder to come by than engineering information. There will be three sources of ecological information: human, printed, and site reconnaissance. Among the human sources will be many of the same persons that have had input into the preliminary portions of the study (Chapter 2). These human resources often can suggest literature pertaining to the sites. Finally, it may be necessary to undertake pilot studies or site reconnaissance to obtain certain types of information. Ecological information is discussed in Section 3.3.

If alternate sites are being considered for energy development, they can be evaluated and compared when the information base is compiled. Wherever similar information is available for all sites, it is organized, arranged, and presented to permit easy comparison between sites. Alternate site selection is discussed in Section 3.4.

Developing a conceptual model is the subject of Chapter 4. The conceptual model systematically organizes data and information from the different sources into a useful, holistic framework. This organization framework helps identify the important elements of the system, while eliminating nonessential elements, to make the field studies more efficient.

3.2 TECHNOLOGICAL INFORMATION

3.2.1 General Information

Review the engineering plans to determine what activities might affect the environment and what perturbations these activities might produce. Note particularly the following types of general information. Using this checklist will assist in making the lists of development activities and environmental perturbations complete and comprehensive.

1. Areas to be set aside and cleared of ground cover.

2. Physical dimensions and locations of structures to be built.

3. Construction and operation schedules.

4. Material to be transported into the site and the location of transportation corridors.

5. Chemical nature of materials to be stored on site and locations and details of storage areas.

6. Materials to be transported off the site and their mode of conveyance.

7. Waste materials and their disposal.

8. Details about liquid, solid, thermal, and gaseous effluents to be released to the environment by facility operations.

3.2.2 Activities

List and categorize all activities and phases associated with the development. Table 3-1 shows two examples of how development activities can be grouped into major categories, or phases, of activities. Each category, in turn, contains many major activities, each with subactivities associated with it. These activities may fall into as many as five levels of detail, or levels of resolution.

For examples, Table 3-2 lists an example of major activities associated with oil shale development, and Table 3-3 gives an incomplete example of how one phase of mine development can be subdivided into five levels of activity. Table 3-4 lists 36 activities associated with surface-mine development.

Identify and list all the possible activities associated with the development project as specified in the engineering plans. Often a single subactivity is associated with more than one major activity. This fact is used in Chapter 4 to organize the information from the lists generated in this section.

3.2.3 Perturbations

While developing activity lists, keep a separate list of anticipated perturbations associated with the activities. A perturbation is a disturbance in an environmental system that results in a detectable change in some characteristic of that system. Perturbations can be man-induced (e.g., logging, planting, spraying, bulldozing) or natural (e.g., earthquakes, violent storms, floods).

Sometimes, however, perturbations are not mentioned in the engineering plans or are not immediately obvious. Therefore, consider each activity carefully and list any environmental perturbations that might be associated with it. Document all perturbations with a statement of how an activity will generate a perturbation. Often this will come from the engineering plans; sometimes it will require an ecological judgment from you.

Sometimes the finished product of an activity, such as a man-made structure, will cause environmental perturbations. Examples of such structures are mining shafts, roads and paved surfaces, unpaved roads, fences, culverts, general barriers, impoundments, transmission lines, pipelines, buildings, underground mines, and land fills. These structures create perturbations simply by being in a particular spot. Careful review of the engineering plans will identify such structures, which must also be listed, along with their anticipated perturbations. Table 3-5 contains examples of perturbations associated with oil shale development.

3.2.4 Documentation

Because circumstances vary greatly from project to project, no attempt has been made in this chapter to suggest a standard documentation format. The lists you generate will provide an initial attempt at associating activities with perturbations. Chapter 4 suggests standard ways of documenting these associations more formally while developing the conceptual model of the ecosystem.

One technique that is helpful for remembering that activities and perturbations both are active processes is to describe each as a verb or a short

Table 3-1. Two examples of major activity phases in energy-development projects. The surface-mining example is from Moore and Mills (1977), and the oil shale example, from C-b Shale Oil Venture (1977).

PHASES OF ACTIVITIES ASSOCIATED WITH WESTERN ENERGY DEVELOPMENT

Surface Mining	Oil Shale Development
1. Exploration	1. Site preparation
2. Mine development	2. Preproduction mining
3. Mine production (ancillary activities)	3. Ancillary facilities
4. Mine production (extraction activities)	4. Commercial facilities
5. Reclamation	5. Operation

Table 3-2. Eleven major activities associated with five phases of oil shale development (C-b Shale Oil Venture 1977)

MAJOR OIL SHALE DEVELOPMENT ACTIVITIES
1. Build/extend roads
2. Build impoundments
3. Sink shafts
4. Mine (development/retort construction)
5. Construct underground facilities
6. Construct surface facilities
7. Process raw materials/operate
8. Build power transmission lines
9. Build staging area (off-tract)
10. Build pipelines (off-tract)
11. Build commercial facilities

Table 3-3. A partial list of activities associated with surface-mine development (Moore and Mills 1977). Note that many activities occur more than once within the five hierarchical levels.

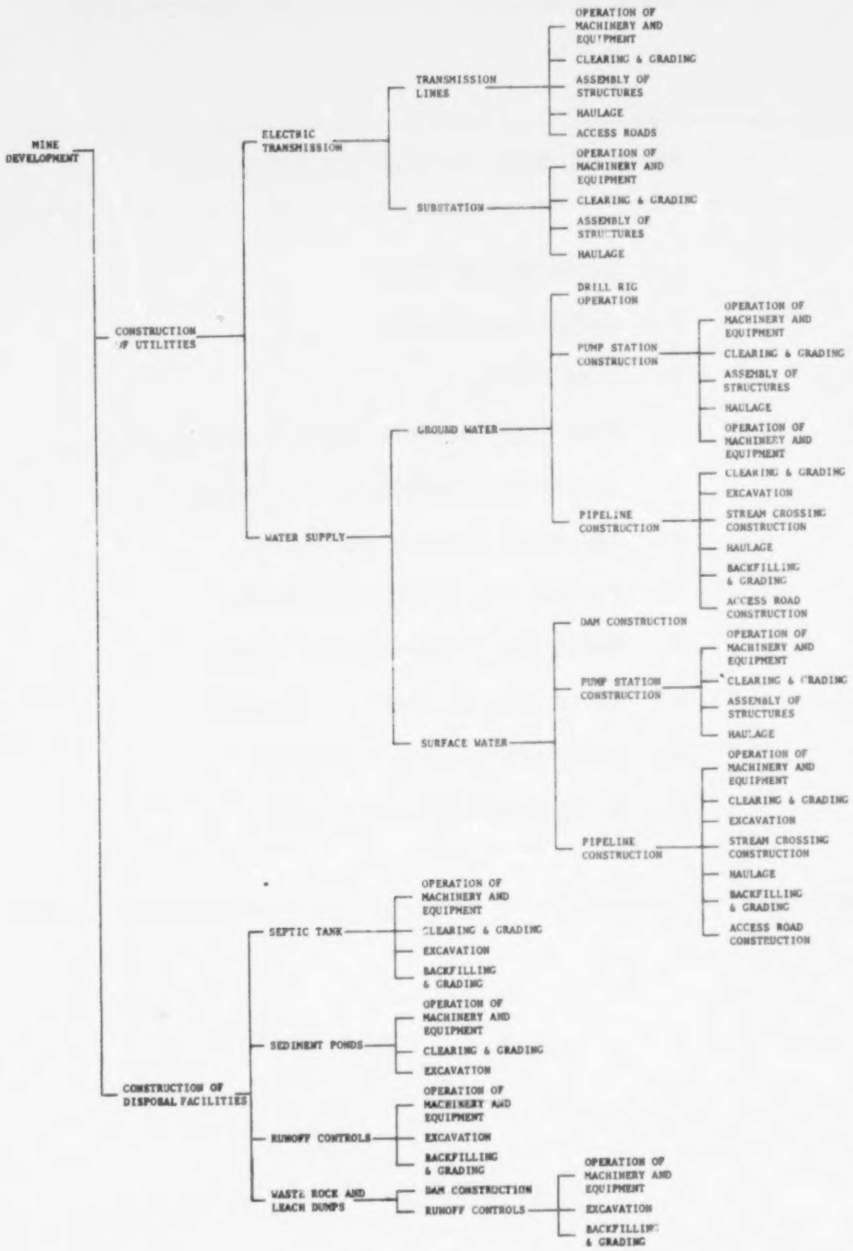

MINE DEVELOPMENT
CONSTRUCTION OF UTILITIES
ELECTRIC TRANSMISSION
TRANSMISSION LINES
OPERATION OF MACHINERY AND EQUIPMENT
CLEARING & GRADING
ASSEMBLY OF STRUCTURES
HAULAGE
ACCESS ROADS
SUBSTATION
OPERATION OF MACHINERY AND EQUIPMENT
CLEARING & GRADING
ASSEMBLY OF STRUCTURES
HAULAGE
WATER SUPPLY
GROUND WATER
DRILL RIG OPERATION
PUMP STATION CONSTRUCTION
OPERATION OF MACHINERY AND EQUIPMENT
CLEARING & GRADING
ASSEMBLY OF STRUCTURES
HAULAGE
OPERATION OF MACHINERY AND EQUIPMENT
PIPELINE CONSTRUCTION
CLEARING & GRADING
EXCAVATION
STREAM CROSSING CONSTRUCTION
HAULAGE
BACKFILLING & GRADING
ACCESS ROAD CONSTRUCTION
SURFACE WATER
DAM CONSTRUCTION
PUMP STATION CONSTRUCTION
OPERATION OF MACHINERY AND EQUIPMENT
CLEARING & GRADING
ASSEMBLY OF STRUCTURES
HAULAGE
PIPELINE CONSTRUCTION
OPERATION OF MACHINERY AND EQUIPMENT
CLEARING & GRADING
EXCAVATION
STREAM CROSSING CONSTRUCTION
HAULAGE
BACKFILLING & GRADING
ACCESS ROAD CONSTRUCTION
CONSTRUCTION OF DISPOSAL FACILITIES
SEPTIC TANK
OPERATION OF MACHINERY AND EQUIPMENT
CLEARING & GRADING
EXCAVATION
BACKFILLING & GRADING
SEDIMENT PONDS
OPERATION OF MACHINERY AND EQUIPMENT
CLEARING & GRADING
EXCAVATION
RUNOFF CONTROLS
OPERATION OF MACHINERY AND EQUIPMENT
EXCAVATION
BACKFILLING & GRADING
WASTE ROCK AND LEACH DUMPS
DAM CONSTRUCTION
RUNOFF CONTROLS
OPERATION OF MACHINERY AND EQUIPMENT
EXCAVATION
BACKFILLING & GRADING

Table 3-4. Comprehensive list of activities associated with surface mine development in the western United States (Moore and Mills 1977)

1. Survey land surface
2. Operate drill rigs
3. Remove surface features
4. Store topsoil materials
5. Dewater
6. Blast
7. Remove overburden
8. Dispose of overburden
9. Extract minerals
10. Replace topsoil and revegetate
11. Irrigate
12. Operate machinery and equipment
13. Clear and grade
14. Excavate
15. Backfill and grade
16. Construct stream crossings
17. Construct dams
18. Assemble structures
19. Cut and fill
20. Haul
21. Prepare surfaces and roadbeds
22. Store minerals
23. Crush minerals
24. Load minerals
25. Operate railroads
26. Operate access roads
27. Operate haul roads
28. Store fuel and chemicals
29. Operate maintenance yards and parking lots
30. Operate electric transmissions
31. Operate water supply
32. Operate sewage treatment plants
33. Operate septic tanks
34. Operate runoff controls
35. Operate waste rock and leach dumps
36. Operate sediment and leach ponds

Table 3-5. Environmental perturbations associated with oil shale development in western Colorado (C-b Shale Oil Venture 1977). Note the categories used to group the perturbations.

ENVIRONMENTAL PERTURBATIONS

Meteorological
- Create fugitive dust
- Create odors
- Create noise and vibration
- Emit steam
  - Create water vapor
  - Create icing
  - Create fog
- Emit particulates and aerosols
- Emit SO_2
- Emit H_2S
- Emit NO
- Emit NO_2
- Emit NO_x
- Emit CO
- Emit CH_4
- Emit NMHC (nonmethane hydrocarbons)
- Emit THC (total hydrocarbons)
- Emit ozone and other oxidants
- Emit arsenic
- Emit mercury
- Emit selenium

Topographic
- Create landslides
- Alter contour of land
- Alter surface drainage patterns

Edaphic
- Create compaction
- Create erosion
- Remove all vegetation
- Alter humus content
- Mix soil profile

Geologic
- Cause ground to subside
- Expose shrink/swell clays

Biological
- Disturb vegetation
- Increase road kills
- Disturb soil microorganisms

Table 3-5 (Continued)

ENVIRONMENTAL PERTURBATIONS
Hydrological
Alter surface runoff
Alter peak flows (flash flooding)
Alter sedimentation
Alter evaporation
Alter seepage
Alter water table levels
Alter downstream flows
Alter stream channels
Alter groundwater chemical composition
Alter groundwater flows

sentence. For example, instead of "road construction," write "build road"; for "excavation," write "excavate"; for "stack emissions," write "emit particulates" (or whatever will be emitted). In other words, be as specific as possible when compiling the lists.

3.3 ECOLOGICAL INFORMATION

3.3.1 Human Sources

Consider the following as sources of information:

1. Representatives from federal, state, and local governmental agencies.

2. Universities: faculties, graduate students, and librarians.

3. Environmental groups, sportsmen's clubs, and agricultural organizations.

4. Interested private institutions, such as museums or foundations.

5. Any other individuals knowledgeable about the area and its ecology: old-time residents, commercial exploration teams, local businesses, consulting firms, etc.

Ask the individuals for the following kinds of information:

1. The presence of any species that is threatened, endangered, unique, or of high social value.

2. Key structural components, or features, of the environmental systems of interest.

3. Potential impacts of the proposed development activity.

4. Any additional sources of information, such as literature, agencies, institutions, other organizations, or specific individuals.

3.3.2 Printed Sources

Collect literature pertaining to the sites under consideration. Include the following:

1. Local flora and fauna, field guides, etc., for the region.

2. Articles from the scientific and popular literature.

3. Theses and dissertations in local libraries.

4. State, federal, and university reports.

5. Maps (U.S. Geological Survey and others), aerial photos, etc.

6. Any other plans and documents about the existing environmental system or the anticipated activity for which the baseline study is being prepared.

3.3.3 Site Reconnaissance and Pilot Studies

The size of the project will determine the amount of effort that goes into site reconnaissance and pilot studies. Site reconnaissance is essentially qualitative. On a small project, two persons (e.g., a wildlife biologist and a plant ecologist) might easily conduct a site reconnaissance in one or two days. Such a study might include qualitative appraisals of wildlife habitat, vegetative communities, and wildlife species present on site. Larger projects might require a team of five to 10 specialists working a week or more in an area. Basically a site reconnaissance is conducted to complement and confirm information from the literature and from human sources. Reconnaissance surveys can also be used to identify sites with serious potential conflicts for development.

A pilot study is essentially quantitative. Pilot studies are used for preliminary analysis to see whether the objectives of the baseline study are reasonable, i.e., whether the demands of the objectives can, in fact, be satisfied within biological constraints of variability. Pilot studies are thus used for sampling populations to determine degrees of variability. This information is used to calculate the size of samples necessary for meeting certain statistical requirements for confidence levels on population estimates.

There is no easy way to establish guidelines for site reconnaissance or pilot studies. However, some qualitative procedures for assessing habitat are discussed in Section 6.3.2. This more-formal approach to site reconnaissance might be necessary for comparing site alternatives for a large project. In such cases, it is essential to gather ecological data from each site being considered in such a way that the data are comparable from site to site.

3.3.4 Types of Information

Within the broad types of information mentioned in Section 3.3.1, look for more specific information that best characterizes the ecosystem, or ecosystems, of interest. This includes information on abiotic factors (air, water, soil, topography, and geology) and biotic factors (flora and fauna). Remember that this is all done preliminary to the field portion of the baseline study. Look for the following information for the initial information base:

1. Elevations and major features of topography.

2. Distribution of soil types.

3. Climatic conditions and their seasonal variations.

4. Location of surface-water bodies.

5. Distribution of vegetative types and plant communities.

6. Distribution of important animals and migration patterns.

7. Identities of other major structural and functional components of aquatic and terrestrial ecosystems.

8. Names and distributions of rare, threatened, or endangered species and their habitats.

9. Identity of special indicator species.

10. Distribution of important economic resources.

3.3.5 Information Organization

Summarize this information in some standard format for easy comparison or review. A concise approach, for instance, is to list major edaphic, topographic, or vegetative classifications across the top of a table. Species arranged according to trophic level or some other system of classification (e.g., life forms) are listed down the left side. Such a multipage table provides a quick check on the presence or absence of a particular species or class (e.g., carnivore, tree) within any spatial unit defined across the top of the table. An example of how this was done in an oil shale baseline study is presented in Table 3-6.

Choose categories carefully, keeping in mind the objectives and constraints of the study. This will help reduce effort wasted on purposeless data gathering during the field portions of the baseline study.

3.4 EVALUATE ALTERNATE SITES

The above-described instructions for compiling and organizing the preliminary information base apply to one site or to many. However, if more than one site is involved, organize the information in such a way that it is comparable among sites. The information base should contain preliminary species lists and other types of inventories as well as technical details of the proposed activity. Survey and compare this information for each site and estimate the degree to which the proposed development will result in changes on each site.

There is no set procedure for doing this. If the information is organized and arranged for direct comparison, evaluating alternate sites on the basis of this preliminary information should not be difficult. If more than one site alternative remains after this step, then a conceptual model and a field study must be done for each remaining site.

The following sections provide a checklist for determining the types of changes that may be brought about in an ecosystem by various development activities:

3.4.1 Abiotic Considerations

1. General changes in air quality.

2. Changes in other air characteristics, local meteorology, and microclimates that affect critical ecosystem components.

3. Changes in water quality.

4. Changes in surface and groundwater hydrology.

5. Changes in water characteristics that affect critical ecosystem components.

6. Changes in soil and subsoil characteristics, physical, chemical, and biological (e.g., at spoil dumps).

3.4.2 Community and Population Considerations

1. Changed species composition and diversity (plant and animal).

2. Changed direction or rate of succession.

3. Changed life-form composition and characteristics.

4. Changed age classes, reproduction, and seed production.

5. Changed abundance or biomass.

6. Altered age and sex ratios.

7. Altered rates of recruitment.

8. Redistributed seasonal activity or areas of concentration.

9. Lost demes or species.

3.4.3 Population and Individual Considerations

1. Changed behavior, both individual and social.

2. Changed feeding patterns.

3. Changed growth rates among immatures.

4. Changed body condition in all age groups.

5. Changed mean longevity (especially woody plants and vertebrates).

6. Changed in vigor of plant species.

7. Changed plant or animal physiology or in chemical constituents of plant or animal tissues.

3.4.4 Peripheral Considerations

Consider the above changes on lands contiguous to the periphery of the site, particularly in the case of stack emission drift or plumes, downstream effects from effluents, noise, road systems, etc.

Table 3-6. Example of a comprehensive listing of autotrophs and mammals in four ecosystems comprising 13 habitat types on an oil shale development site in western Colorado (C-b Shale Oil Venture 1977). Only a few examples are listed in some categories. Note how plants and animals are grouped according to functional role in the ecosystem. This type of preliminary grouping facilitates development of the conceptual model for the ecosystem.

AUTOTROPHS IN FOUR ECOSYSTEM TYPES

		Forest Upland	General Upland					General Bottomland					Aquatic	
Major Group	Species	Pinyon-Juniper	Chained Range-land	Bunch-grass	Sage-brush	Mixed Mt. Shrub	Rabbit-brush	Grease-wood	Sage-brush	Wild Rye	Ri-parian	Agri-cultural Meadow	Stream	Pond & Marsh
Trees	Box Elder										x			
	Douglas Fir	x												
	Narrowleaf Cottonwood										x			
	Pinyon Pine	x	x		x									
	Rocky Mountain Juniper	x												
	Siberian Elm	x	x											
Shrubs	Antelope Bitterbrush	x	x		x									
	Big Sagebrush	x	x		x				x	x				
	Chokecherry					x								
	Currant					x								
	Four-Winged Saltbush			x										
	Gambel's Oak	x	x											
	Golden Currant					x								
	Greasewood							x		x				
Annual Grasses & Forbs	Annual Sourge													
	Baby Blue-Eyes	x	x		x	x								
	Barnyard Grass											x		
	Bee Plant							x						
	Cheatgrass	x	x	x	x			x	x			x		
	Chorispora													
Perennial Graminoids	Baltic Rush										x			x
	Blue-Bunch Wheatgrass	x	x											
	Blue Grama	x	x						x					
	Bluegrass	x												
	Cattail													x
	Common Reed										x			x
	Crested Wheatgrass	x	x		x			x						
Perennial Forbs	Actinea	x	x											
	Alfalfa										x			
	Alum Root		x											
	Aster	x	x		x			x						
	Aster Adscendens					x								
	Balsam Root	x	x		x									
	Bastard Toadflax	x	x		x							x		
	Beard Tongue		x	x										

Table 3-6 (Continued)

MAMMALS IN FOUR ECOSYSTEM TYPES

			Forest Upland	General Upland					General Bottomland					Aquatic	
Major Group	Species Groups	Species	Pinyon-Juniper	Chained Range-land	Bunch-grass	Sage-brush	Mixed Mt. Shrub	Rabbit-brush	Grease-wood	Sage-brush	Wild Rye	Ri-parian	Agri-cultural Meadow	Stream	Pond & Marsh
Small Mammals	Shrews	Water Shrew										x		x	x
		Dwarf Shrew													
		Vagrant Shrew		x								x	x		
		Merriam's Shrew													
		Masked Shrew		x	x							x	x	x	x
	Bats	Townsend's Big-Eared Bat	x	x	x	x	x	x	x	x	x	x	x		
		Pallid Bat	x	x	x	x	x	x	x	x	x	x	x		
		Silver-Haired Bat	x	x											
	Squirrels	Richardson's [illegible] Squirrel							x						
		Golden Mantled Ground Squirrel	x	x	x	x	x	x	x	x	x				
	Mice	Deer Mouse	x	x	x	x	x	x	x	x	x	x	x		
		Pinon Mouse	x	x											
		House Mouse											x		
		Western Jumping Mouse					x								
		Apache Pocket Mouse		x		x							x		
	Rats	Bushy-Tailed Woodrat	x	x			x		x						
	Voles	Meadow Vole										x			
		Montane Vole			x	x	x								
		Long-Tailed Vole			x	x	x					x			
		Sagebrush Vole			x	x	x								
	Gophers	Northern Pocket Gopher		x	x	x						x	x		
	Chipmunks	Least Chipmunk	x	x	x	x	x	x	x	x	x	x			
		Colorado Chipmunk	x	x	x	x	x								
		Uinta Chipmunk	x	x	x	x	x								
Medium-Sized Mammals	Rabbits	White-Tailed Jackrabbit	x	x	x	x	x	x	x	x	x	x	x		
		Desert Cottontail	x	x	x	x	x	x	x	x	x	x	x		
	Rodents	Yellow-Bellied Marmot											x		
		Beaver													
		Muskrat													
		Porcupine													
	Carnivores	Coyote	x	x	x	x	x	x	x	x	x	x	x		
		Raccoon	x									x	x	x	x
		Ermine		x			x				x	x			
		Long-Tailed Weasel	x	x		x	x			x		x	x		
		Badger			x	x	x			x			x		
		Striped Skunk										x	x		
		Bobcat	x	x	x	x	x	x	x	x	x	x			
Large Mammals	Ungulates	Elk	x	x	x	x	x								
		Mule Deer	x	x	x	x	x	x	x	x	x	x	x		

4.0 DEVELOP THE CONCEPTUAL MODEL

4.1 INTRODUCTION AND OVERVIEW

An environmental system contains living things interacting with both the nonliving environment and each other. The system, therefore, should be viewed in its entirety, rather than as a collection of unrelated objects. We must now organize this collection according to our perspective of how the objects interact.

This organizational framework, which can be termed a systems approach, produces a conceptual model of the system. A model is merely an abstraction that tries to capture the essential portions of a system in less detail than would be required to reconstruct the entire system. For example, simple verbal descriptions of ecological interactions are models, word models in this case. Topographic maps are models. Matrices and box-and-arrow diagrams, such as we will develop, are also models.

The systems approach exploits the organizational power associated with different types of model building to array, analyze, and integrate environmental data and information so we can improve our understanding of the ecosystem and our ability to predict what will happen to that system if it is stressed by human-controlled or natural influences.

By using a systems orientation, we can organize the information base into a qualitative conceptual model from which we can (1) begin to understand the functioning of the ecosystems on the development site; (2) identify ecological components and processes that should be considered in a baseline study; (3) delineate the spatial and temporal boundaries of the ecosystem; and (4) suggest longterm monitoring and mitigation programs, if necessary.

The purpose of developing a conceptual model of the ecosystem, using matrices and box-and-arrow diagrams, is to identify the important ecological parameters to measure in the field portion of the baseline study. Often such studies inventory plants and animals and gather numerical data on many types of ecological parameters simply because they are easy to measure. The conceptual model permits the investigators to choose, from a virtually infinite number of possible ecosystem measurements, those measurements that are most important both from an ecological standpoint and from the broader perspective of development activities.

4.1.1 Conceptual Model of the Ecosystem: An Overview

The information base developed by procedures described in Chapters 2 and 3 now becomes a starting point for identifying gaps required in the decision process. The conceptual model is developed using this information base and sound ecological reasoning. When completed, the model serves as a filter to select only those ecosystem attributes and their parameters that are important enough to be studied in the field.

The systems approach to ecological baseline studies described here is a systematic, efficient way to organize information about both the project being developed and the ecosystem. This organization begins with the display of existing information, which very likely includes details that are relatively unimportant to the overall study. The conceptual model reorganizes this information in a meaningful way to eliminate extraneous detail.

The first stage in developing the model uses a systematic, stepwise procedure to associate the development activities with the environmental perturbations they produce. This process first assures that no activities or perturbations are overlooked, then aggregates items wherever possible to remove redundancies that appeared in the early lists of the information base. The result is a comprehensive but relatively compact list of environmental perturbations expected to be produced by the project.

In the next stage of model development, structural components of the ecosystem that either are significant ecologically or which might be potentially impacted by perturbations are systematically identified from the lists of the information base. The degree of detail is specified, temporal factors are considered, important geographic areas are identified, and finally the components themselves are selected.

Ecosystem dynamics are controlled by flows of matter and energy. These flows, in turn, are controlled by physical and biochemical processes. The third stage in model development selects important flows of the ecosystem and the processes that control them.

The fourth stage develops an impact matrix that associates the perturbations with the important ecological components and processes. This matrix uses a ranking system to assess the anticipated impact of each perturbation on each component and process.

Finally, the control diagrams are built. The process, or flow-control, diagrams focus on the natural and man-induced effects that influence each process. The system-control diagrams delineate the interactions between processes, flows, and components of the ecosystem, and consider outside influences, such as climatic impacts and perturbations.

The impact matrix and control diagrams are then used to select those attributes of the ecosystem components that will need to be measured and studied in the field portion of the ecological baseline study.

4.1.2 Documentation

Often the biologist must decide, on the basis of his own expertise, the relative importance of ecological components in an ecosystem or the relative importance of a perturbation. Such a judgment is extremely complex and often highly subjective. He must therefore document any such evaluations with substantive reasoning supporting the evaluation. Not only is this documentation useful for making other decisions based on the judgmental evaluation, but also it serves as a permanent record of how decisions were made.

There are four areas in which documentation is especially important:

1. Description of the location, duration, size, and extent of development activities, including magnitude and duration of perturbations resulting from those activities.
2. Definition of components and processes for inclusion in a conceptual model.
3. Rank of the relative significance of environmental perturbations as they affect ecological components and processes.
4. Rank of the relative importance of various attributes in regulating ecological processes.

Standardized forms are suggested in this manual to facilitate this written documentation.

4.1.3 Building the Model: A Rationale

The information base collected thus far includes details about the proposed activity and both qualitative and quantitative information about the environmental system under consideration. This information falls into three broad categories: perturbations, components, and processes.

A perturbation is a disturbance in an environmental system that results in a detectable change in a component or process of that system. Perturbations can be man-induced (e.g., logging, planting, spraying, bulldozing) or they can be natural (e.g., earthquakes, violent storms, floods).

A component of an ecosystem is a structural element of that system. It is usually an arbitrarily defined unit of an ecosystem that constitutes some abiotic or biotic feature, such as wind, woody plants, small mammals, a particular species, precipitation, soil, etc.

A process is a functional activity that regulates the flow of energy or matter between two components of that system. For instance, photosynthesis is one of the processes regulating the flow of carbon between the atmosphere and plants.

The following criteria are used to select relevant information from the base for the model:

1. Will a specific development activity create perturbations that affect ecosystem components or processes?

2. Is a given component or process intrinsically important to the structure or function of the ecosystem?

The subsections below develop a rationale for, and explanation of, each stage in the development of the conceptual model.

4.1.3.1 Perturbations. Perturbations are identified in a systematic selection process involving two or three matrices. The matrices are two-dimensional checklists that serve as convenient "thought organizers" and help ensure that all possibilities are considered.

It may be desirable to relate major activities of the project to their actual development time frame. If so, a development matrix is used. Major development phases are listed across the top, and the major activities associated with each phase are listed down the side. Checks in the matrix are used to identify their interrelationships.

Whether a development matrix is used or not, an activity matrix is the next step. The information base provides a comprehensive list of all development activities. These can usually be divided into two or more categories. (If possible, it is useful to limit the categories to two to avoid increasing complexity.) Major activities are listed across the top, and subactivities associated with the major activities are listed down the side. Again, the interrelationships between them are noted with a check in the appropriate cell.

The last matrix is the perturbation matrix. The subactivities identified and listed down the vertical axis of the activity matrix are moved directly to the perturbation matrix, where they now are listed across the horizontal axis. Environmental perturbations associated with the development subactivities are listed down the side and associated with subactivities by checks in the intersecting cells.

The perturbations that are thus identified constitute one of the major inputs to the final impact matrix, as explained in Section 4.1.3.4.

4.1.3.2 Components. To identify important ecosystem components, we must consider the spatial dimensions of the system: length, width, and height. A fourth dimension is time, and a fifth important consideration is aggregation. Aggregation is the degree to which we clump or separate elements of the ecosystem for study. All of the above characteristics define the system conceptually in terms of space, time, and structure. How can we identify the combination of characteristics that best describes the ecosystem, or ecosystems, we wish to measure?

The answer lies in the concepts of response and resolution. We want to know when a change has occurred in the system, or, more specifically, how certain elements of that system have responded to man-induced perturbations.

The concept of response, then, is important for choosing the size of the area we want to study and for choosing how much we can aggregate structural components and still detect the response. The degree of aggregation is called resolution. If we lump all trees, shrubs, forbs, and grasses into a group called "vegetation," we have high aggregation and low resolution; if we choose to look at many different species individually, aggregation is low, but resolution is high.

The first task is to review the ecological information base and reduce it to a workable size. In other words, we must clearly define the ecosystem, the elements of that system we wish to study, and the levels of organization for the study.

The concept of levels of organization is fundamental to biology (Figure 4-1). The ecologist is usually concerned with five levels (Miller 1975): organisms, populations, communities, ecosystems, and the ecosphere. For the moment we will concern ourselves only with the first four levels. Later it might be necessary to look at some of the more detailed levels of organization, such as organ systems, organs, and tissues.

Each level of organization is actually a system of interacting components. Each system comprises certain structural components interacting through various functional relationships. The concept of structure and function is thus central to ecology. An organism is a system of organs that interact through various physiological processes; a population is a system of organisms that interact through various physiological and physical processes; and so forth.

An ecosystem consists of abiotic and biotic components (the structure of the system) that interact through physical, chemical, and physiological processes (the functions of the system). The structure of an ecosystem includes the quantity and distribution of chemicals; the range of climatic and physical conditions; the availability and distribution of energy throughout the system; and the number and kinds of different living species and their patterns of distribution (Miller 1975). This structure is determined by flows of matter and energy through the system, and the flows themselves are regulated by the functional processes of the system.

To amplify an earlier definition, a component is an arbitrarily defined unit of classification that is an abiotic or biotic element of an ecosystem, such as a geographical or topographical feature (e.g., stream, bottomland upland), a growth form (e.g., trees, forbs, small mammals), a functional class (e.g., predators, raptors, herbivores), a group of species, a species, or a group of organs (e.g., leaves, stems, roots). We define components in such a way that they reflect our perception of the ecosystem. In no way do components attempt to represent the entire system; rather, they represent those portions of the system that we have defined as important to study, and at a level of resolution that is workable.

Temporal definition for the field study has two aspects: Total time frame (time horizon) and seasonality. The time horizon for the study will very likely be defined by the plans for development. Seasonality, however, has important implications for sampling. Many, if not most, ecological processes are profoundly influenced by seasonal changes, so these changes must be considered carefully when planning a baseline study. Natural seasonal variations will determine sampling frequencies, durations, and intensities for most biota and for many abiotic system measurements.

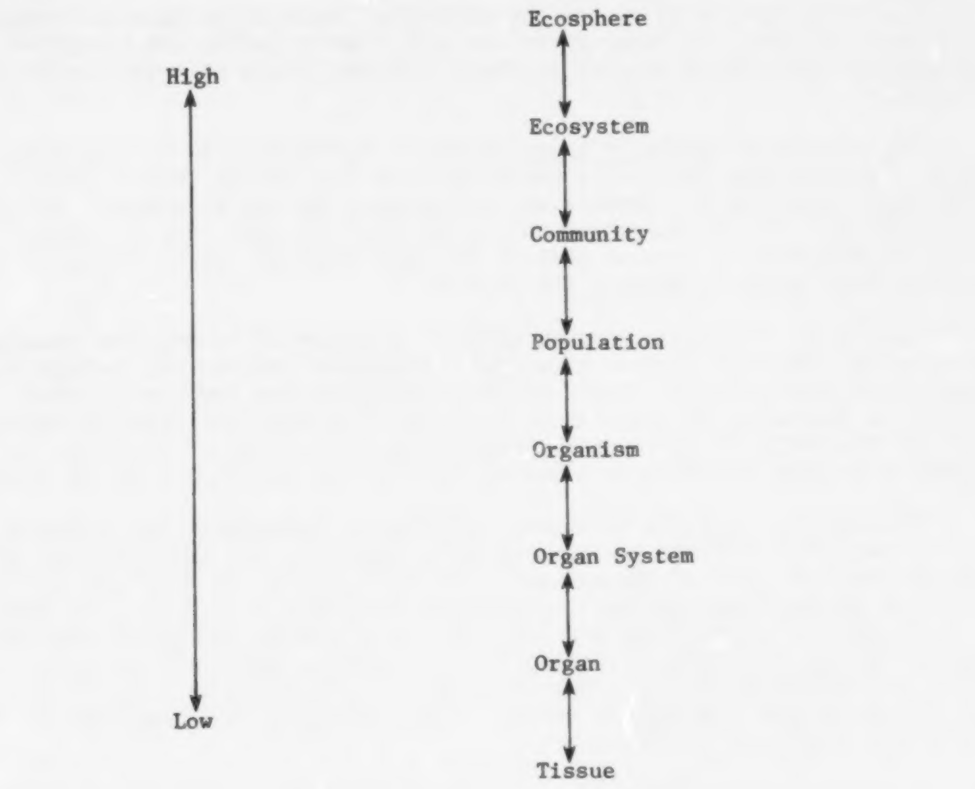

High
Low
Ecosphere
Ecosystem
Community
Population
Organism
Organ System
Organ
Tissue

Figure 4-1. Levels of biological organization.

Ideally a baseline study should run for several decades because of year-to-year variations. Unfortunately, we are not permitted the luxury of the ideal, so we design the study schedule within time constraints imposed by conditions usually beyond our control.

Next, ecological response units are identified. An ecological response unit (ERU) is a geographical unit of land that (1) possesses common vegetative, topographic, elevational, and edaphic or aquatic characteristics, and (2) responds to environmental influences more or less uniformly throughout. In some cases, an ERU may simply be a vegetative community; in others, it may encompass several vegetative communities. The key to selecting an ERU is the likelihood of how it will respond to environmental influences as a unit.

Finally, the ecosystem components themselves must be defined according to our perception of the ecosystem or ERU we are studying. Components are also called variables because they usually vary over time and space. They can be further classified broadly according to their relationships to an ecosystem. One class is called driving variables. As the name implies, driving variables provide input to the ecosystem from without, and in a sense they "drive" the system. These components are external in that they affect the ecosystem without themselves being affected by it. Examples of driving variables are insolation or precipitation. Driving variables are usually abiotic components, with the possible exception of certain man-influenced inputs, such as pesticides, herbicides, fertilizers, plantations, pollutants, manipulatory treatments, etc.

Components that influence each other through abiotic or biotic feedback mechanisms are called state variables. They are parts of the system, and collectively they characterize the "state" of the system at any point in time. These components are within the system, and they interact with each other sufficiently to affect each other's behavior. An example would be trees as they affect the development of nearby vegetation through shading, root competition, and other influences.

An ecosystem component bears a descriptive label, a name, such as grasses, fishes, small mammals, topography, whitetail deer, etc. Each component usually has several attributes that ecologists measure, such as biomass, nitrogen content, slope, numbers, etc. Table 4-1 contains some examples of components and their attributes. Selection of attributes is discussed in Chapter 5.

In identifying important components, sound biological expertise and judgment must be used, based on specific needs, and not on some preconceived and arbitrary classification scheme. The purpose of identifying components in this way is to produce something that is functional and that satisfies the intent of the study. Often groupings will have to be reconsidered, and sometimes the component list will be modified or restructured as the planning for a field baseline study continues. The list of components is used in developing flow diagrams, control diagrams, and the impact matrix.

4.1.3.3 Processes. The quantity and qualities of any ecosystem component are determined by the accumulation of matter and energy in that component. Living things store and discard carbon, nitrogen, calcium, phosphorus, and many other chemicals as they pass through their life cycles. The law of conservation of matter assures us that matter can be neither created nor

Table 4-1. Examples of ecosystem components and some of their attributes.

Component	Attribute
Air	Temperature Relative humidity Potential evaporation Trace metal content
Water	Temperature Dissolved oxygen pH Conductivity
Soil	Temperature Moisture content Texture
Producers	Biomass Density Diversity Relative abundance
Consumers	Population age structure Relative abundance Biomass Density Food habits

destroyed, that it is simply re-arranged. It is relatively easy, then, to conceive of matter and energy flowing through the ecosystem, stopping briefly in components along the way, but eventually flowing on. A particular form of matter or energy that flows among ecosystem components is called a flow currency. Common flow currencies are carbon, nitrogen, phosphorus, heat, water, and biomass.

The flows of these currencies are controlled by various types of physical, chemical, and biological processes; and the processes themselves are controlled by the components, both driving and state variables. For instance, as plants grow, they accumulate carbon. The main process controlling the flow of carbon into a plant is photosynthesis. However, the process of photosynthesis is affected by changes in air temperature, ambient humidity, light, soil moisture, and even by certain characteristics of the plant itself. The plant, in turn, has some effect on the surrounding microclimate, and it thus interacts with some of the components that influence photosynthesis. Processes thus are affected by both driving and state variables, and the quantity of any component is determined by flows of matter and energy into that component and the storage capacity of that component.

The next task, in designing the field portion of a baseline study is to select flow currencies that allow us to link the components we have selected. Components are linked conceptually by using simple diagrams that trace the flow of a particular currency through the ecosystem. The choice of flow currencies depends on (1) what the components are, (2) how common a currency is to a set of components, and (3) how easy the currency is to measure in the system.

Because each flow currency provides a linkage between ecosystem components, all components linked by a particular currency may be considered conceptually as a subsystem of the ecosystem being studied. These are called flow currency subsystems, and they are represented by box-and-arrow diagrams known as flow diagrams. An example of a carbon subsystem diagram is presented in Figure 4-2.

These diagrams are developed using a simple flow matrix, also known as a coupling matrix, that identifies the flow of currency from one component to another. In this type of matrix, all ecosystem components are listed across the top and down the left side in the same order (Figure 4-3). Sources and sinks are sometimes added for conceptual clarity. They are considered to be outside the system of interest. Conceptually they can supply or receive an infinite amount of flow currency. Thus, in the case of water (Figure 4-3), a source and sink are specified. In the case of carbon, source and sink are combined. Either way is acceptable.

From the coupling matrix it is relatively easy to draft a flow diagram for each flow currency subsystem. This has been done in Figures 4-4 and 4-5, based on the coupling matrix. One of the reasons for choosing different flow currencies, rather than basing the entire system flow diagram on one currency, is to get the flow subsystems down to a manageable size. The common denominator for all ecological systems is energy, but a single diagram of an ecosystem based on energy alone would be extremely complicated.

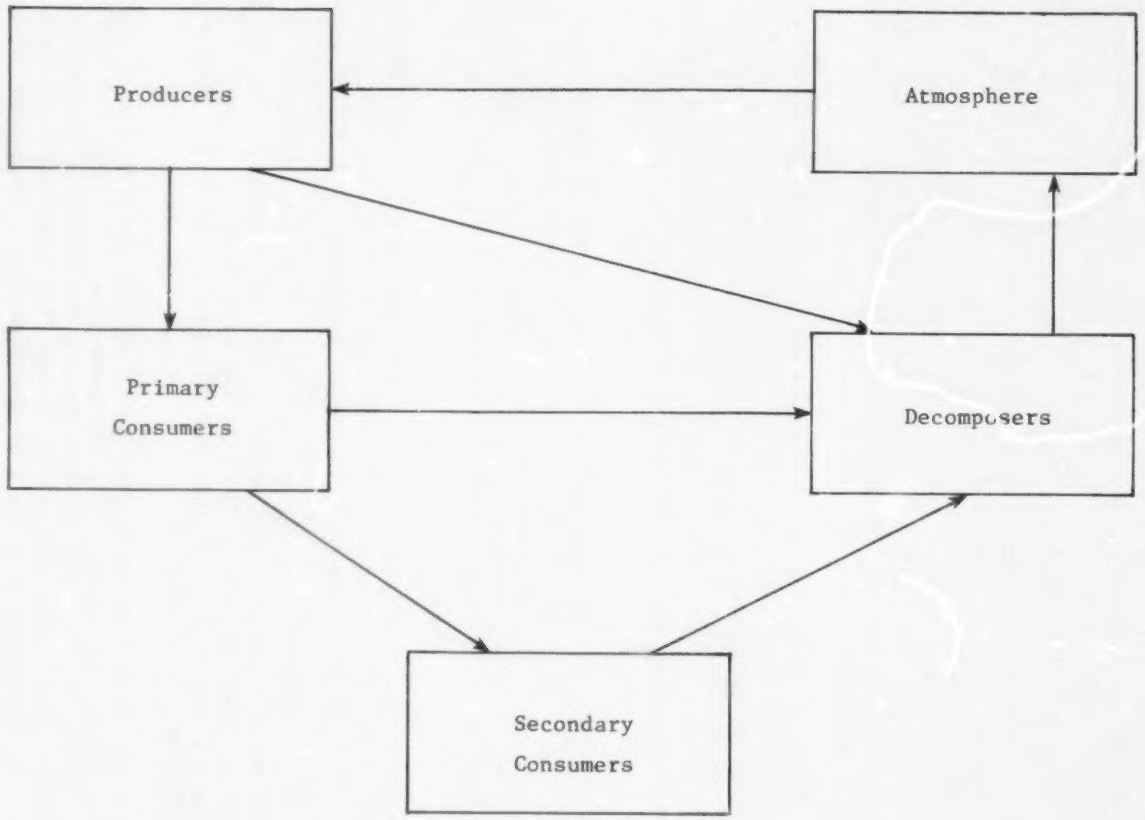

Producers
Atmosphere
Primary Consumers
Decomposers
Secondary Consumers

Figure 4-2. Example of a flow currency subsystem diagram showing how ecosystem components can be linked conceptually by flows of matter or energy. The flow currency chosen for this example is carbon. The level of resolution is very low.

	Components	1. Source	2. Standing vegetation	3. Litter	4. Soil horizon A	5. Soil horizon B	6. Soil horizon C	7. Sink	8. Source & Sink	9. Live plants	10. Standing dead	11. Plant litter	12. Microflora	13. Soil organic matter	14. Herbivores	15. Omnivores	16. Carnivores	17. Soil fauna	18. Animal litter
Water	1. Source		x	x	x														
	2. Standing vegetation			x	x														
	3. Litter				x														
	4. Soil horizon A					x													
	5. Soil horizon B						x												
	6. Soil horizon C							x											
	7. Sink																		
Carbon	8. Source & Sink									x			x						
	9. Live plants										x	x	x		x	x			
	10. Standing dead											x	x		x	x			
	11. Plant litter								x				x					x	
	12. Microflora													x					
	13. Soil organic matter								x				x					x	
	14. Herbivores								x							x	x		x
	15. Omnivores								x							x	x		x
	16. Carnivores								x										x
	17. Soil fauna								x										x
	18. Animal litter								x				x					x	

Figure 4-3. Flow, or coupling, matrix illustrating how ecosystem components are coupled by flows of water and carbon through the ecosystem. An X in a cell indicates that a flow exists from the component at the side into the component at the top.

WATER SUBSYSTEM

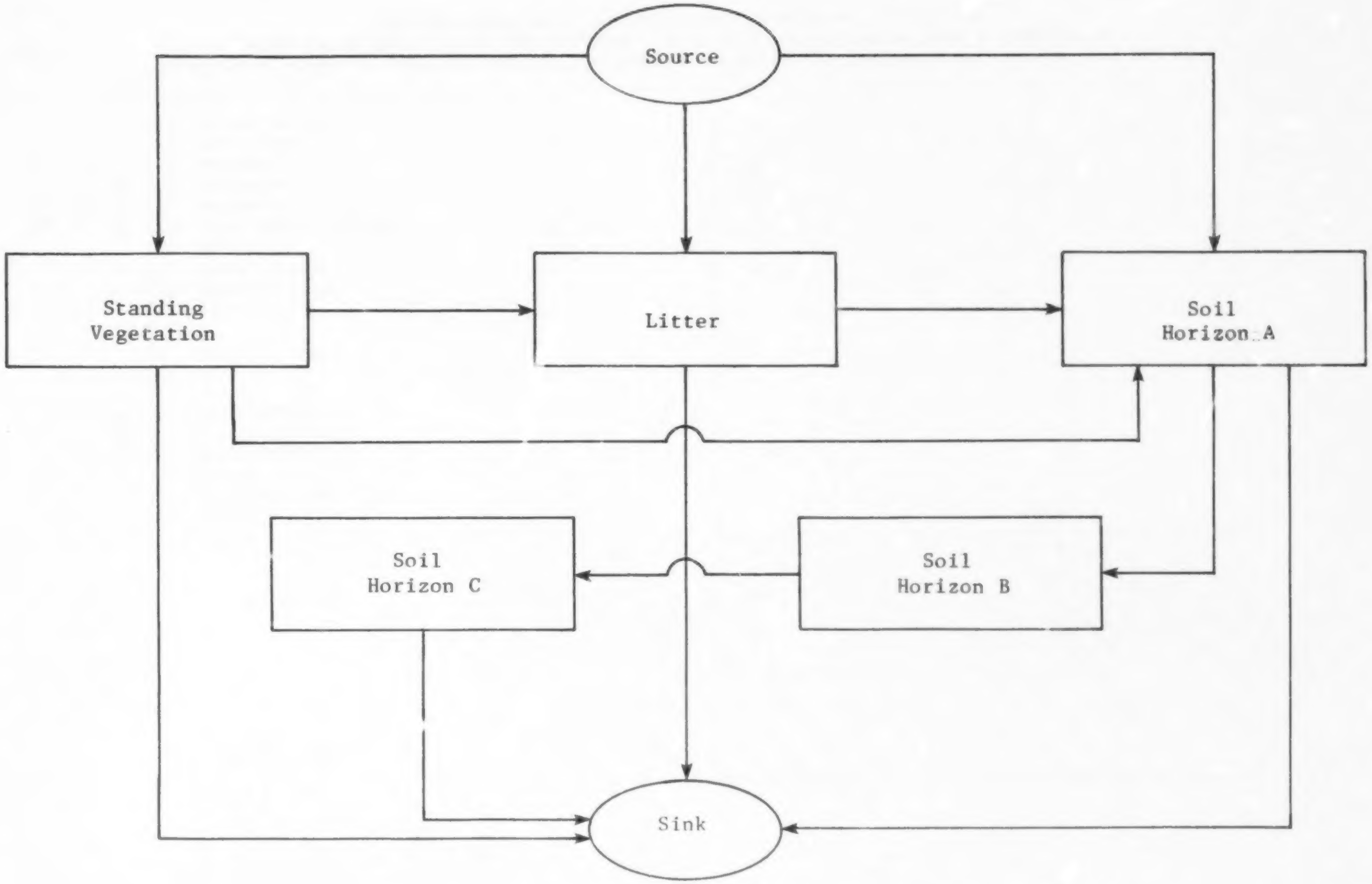

Source
Standing Vegetation
Litter
Soil Horizon A
Soil Horizon C
Soil Horizon B
Sink

Figure 4-4. Flow diagram for water flow through the ecosystem. Ovals are sources and sinks; rectangles are system components.

Carbon Subsystem

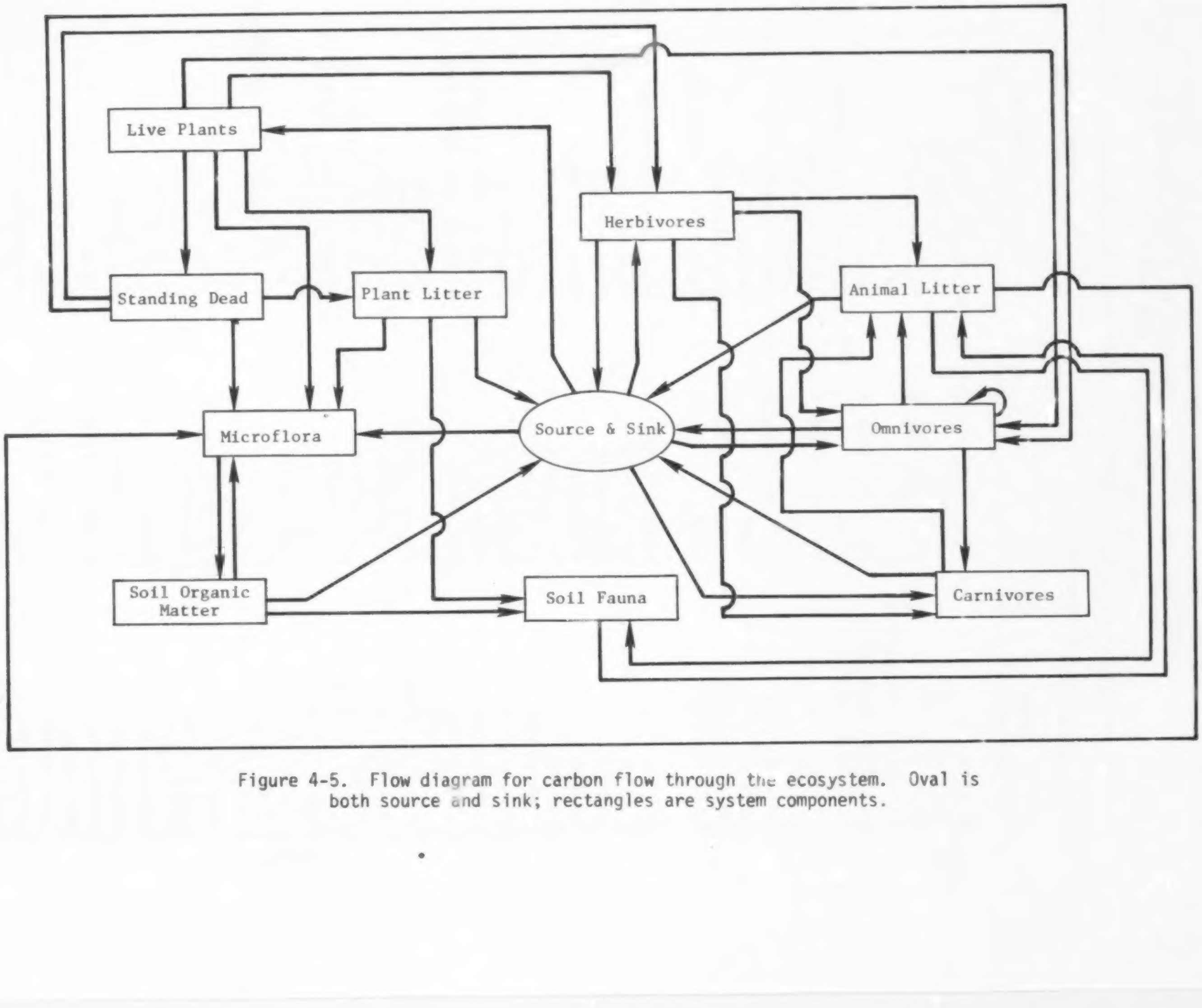

Live Plants
Herbivores
Standing Dead
Plant Litter
Animal Litter
Microflora
Source & Sink
Omnivores
Soil Organic Matter
Soil Fauna
Carnivores

Figure 4-5. Flow diagram for carbon flow through the ecosystem. Oval is both source and sink; rectangles are system components.

Table 4-2. Example list of processes controlling flows of water and carbon throughout the ecosystem. These processes are directly related to flows depicted in Figures 4-4 and 4-5

	Components		Processes
	From	To	Process
Water	Source	Standing vegetation	Precipitation
	Source	Litter	Precipitation
	Source	Soil horizon A	Precipitation
	Standing vegetation	Litter	Dripping
	Standing vegetation	Soil horizon A	Dripping
	Standing vegetation	Sink	Evapotranspiration
	Litter	Soil horizon A	Infiltration
	Litter	Sink	Evaporation
	Soil horizon A	Soil horizon B	Percolation
	Soil horizon A	Sink	Evaporation
	Soil horizon B	Soil horizon C	Percolation
	Soil horizon C	Sink	Subsurface drainage
Carbon	Source	Live plants	Photosynthesis and respiration
	Source	Microflora	Photosynthesis and respiration
	Source	Herbivores	Immigration
	Source	Omnivores	Immigration
	Source	Carnivores	Immigration
	Live plants	Standing dead	Death
	Live plants	Microflora	Shattering
	Live plants	Herbivores	Grazing and browsing
	Live plants	Omnivores	Grazing and browsing
	Live plants	Plant litter	Shattering
	Standing dead	Plant litter	Shattering
	Standing dead	Microflora	Decomposition
	Standing dead	Herbivores	Grazing and browsing
	Standing dead	Omnivores	Grazing and browsing
	Plant litter	Microflora	Decomposition
	Plant litter	Soil fauna	Eating
	Plant litter	Sink	Wind removal and decomposition
	Herbivores	Animal litter	Death
	Herbivores	Omnivores	Predation
	Herbivores	Carnivores	Predation
	Herbivores	Sink	Emigration
	Omnivores	Omnivores	Predation
	Omnivores	Carnivores	Predation
	Omnivores	Animal litter	Death
	Omnivores	Sink	Emigration
	Carnivores	Animal litter	Death
	Carnivores	Sink	Emigration
	Animal litter	Microflora	Decomposition

Table 4-2 (Continued)

	Components		Processes
	From	To	Process
Carbon	Animal	Sink	Decomposition
	Animal litter	Soil fauna	Eating
	Microflora	Soil organic matter	Decomposition
	Soil fauna	Animal litter	Death
	Soil organic matter	Microflora	Decomposition
	Soil organic matter	Soil fauna	Eating
	Soil organic matter	Sink	Decomposition

Once the flows are identified, it is necessary to list the physical, chemical, or biological processes that control those flows. An example of how this would be done for Figures 4-4 and 4-5 is presented in Table 4-2. These are examples of only one way it might be done; they are not comprehensive checklists. Each ecosystem and development site is virtually unique and must be treated accordingly. A conceptual model must be tailored to a specific site, although often it is possible to obtain insights into one location from a conceptual model developed for another site. The list of processes is used in developing the impact matrix and the control diagrams.

4.1.3.4 The Impact Matrix. To this point, through a systematic selection process, we have identified potentially important environmental perturbations that might affect the biota of the ecosystem, and we have listed important components and processes of the ecosystem. The impact matrix is the first step in relating these three groups of things to each other in a meaningful way; it integrates the lists of environmental perturbations with ecosystem components and processes to address the question: What are the effects of the perturbations on the ecosystem?

Perturbations are listed across the top of the matrix. These perturbations can impact ecosystem components in two ways: (1) directly upon the component itself; and (2) indirectly through the processes that control energy and material flows into and out of the component. Apart from such obvious effects as physical removal of vegetation, grading soil, etc., most effects work through the ecological processes. Therefore, most of the processes we have identified will be listed down the left side of the impact matrix, along with those components that are directly affected by perturbations. The effects are then numerically ranked, as explained in Section 4.5. The ranking system helps the investigator to set priorities for the field portion of the ecological baseline study.

The impact matrix, then, is a key product that can be used extensively, not only for planning field baseline studies, but also for long-term monitoring and mitigation, if necessary.

4.1.3.5 Control Diagrams. The impact matrix is a convenient and concise way of showing where perturbations affect the ecosystem. However, ecosystem components also affect the system through physical and biological feedback mechanisms, so we must now look more closely at these effects.

Any system is a collection of objects which, by their interaction and interdependence, form an entirety that functions in a particular way. Often components of that entirety interact to confer on the system certain emergent properties that might not readily be inferred from a study of the component parts separately. First-, second-, and higher-order interactions cause the system to behave uniquely as a functional unit rather than as the simple sum of all the component activities. In other words, because of synergistic effects, the system takes on behavioral characteristics that transcend the characteristics of its component parts.

As explained elsewhere, these component parts, the state and driving variables, are linked to each other by flows of matter or energy (flow currencies), and they interact with each other through these flows. Processes of the system act as valves that regulate the flows: as the rate of a process changes, the flow rate changes, and the state variable dependent on that flow is affected. Processes are regulated by driving variables and state variables, the latter often occurring through feedback.

Section 4.6 explains how to construct two types of diagrams showing how the important feedback mechanisms of the system work. From these diagrams we can look at higher-order effects and secondary impacts in order to identify more clearly the attributes of ecosystem components that should be measured in the field portion of the ecological baseline study.

The first of these, the flow-control, or process, diagram, focuses on a single process and the components and perturbations that affect it. It is used for cause-effect reasoning about how various factors influence the system. Figure 4-6 presents a general example of a process diagram. It contains both natural and man-induced driving variables, state variables, important attributes of all variables, donor and receiver components, and the controlling process.

The steps thus far have enabled us to address the functioning of the ecosystem: how the ecosystem operates to produce the ever-shifting dynamic changes characteristic of systems that are fundamentally biological. The flow-control diagrams illustrate the great complexity of such a system by focusing on the several factors affecting any single process. It remains to show how important ecosystem components interact with each other through their effects on the processes. (Remember, the components of interest are far fewer than the total number of components considered initially). This is done in the system-control diagram.

Each flow currency links components of a distinct subsystem. Carbon or energy are two of the most common currencies, and the classic flows of these currencies through various trophic levels can be found in every ecology textbook. Water is another common currency, and its flow through an ecosystem is often related to carbon flow, and vice versa. To simplify things conceptually, however, we must keep them as separate flows, and attempt to link the currency subsystems with information flows between the subsystems themselves.

Flows of information can be viewed as conversion factors: e.g., a particular number of animals will have a given effect on carbon flow by decreasing the plants; or, conversely, as plant biomass (carbon) increases, animal biomass (kilograms) might increase also. The relationship between the two can be defined mathematically, although explicit mathematical definitions among processes and components are beyond the scope of this manual. This is what is meant by information flow between subsystems, however.

Information flows are classified into three types for ease of identification (Figure 4-7). The first type is the flow linking state variables from one subsystem to a process in another subsystem. A second type links the state variables in a particular subsystem to a process within that same subsystem. This type is known as a "feedback" loop, or cybernetic linkage. A third type of information linkage originates at the driving variables and provides input to those processes influenced by driving variables. Information flows imply causal relationships, although the explicit nature of that relationship may not be known.

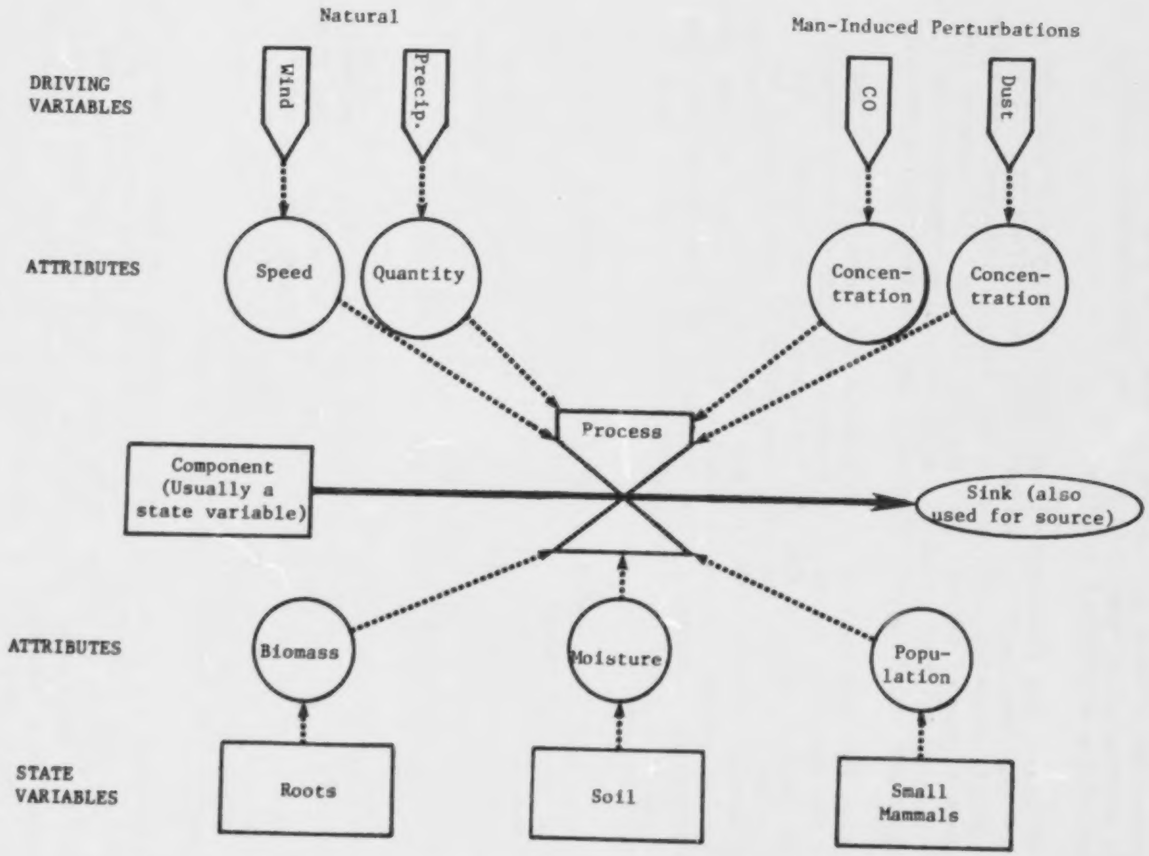

Natural
Man-Induced Perturbations
DRIVING VARIABLES
Wind
Precip.
CO
Dust
ATTRIBUTES
Speed
Quantity
Concen-tration
Concen-tration
Process
Component (Usually a state variable)
Sink (also used for source)
ATTRIBUTES
Biomass
Moisture
Popu-lation
STATE VARIABLES
Roots
Soil
Small Mammals

Figure 4-6. A generalized process diagram containing examples of common variables. Solid arrow depicts flow of some currency (matter or energy) through the ecosystem between two components or between a component and either a source or a sink. Broken arrows represent flows of information, or various influences, of ecosystem components on the process.

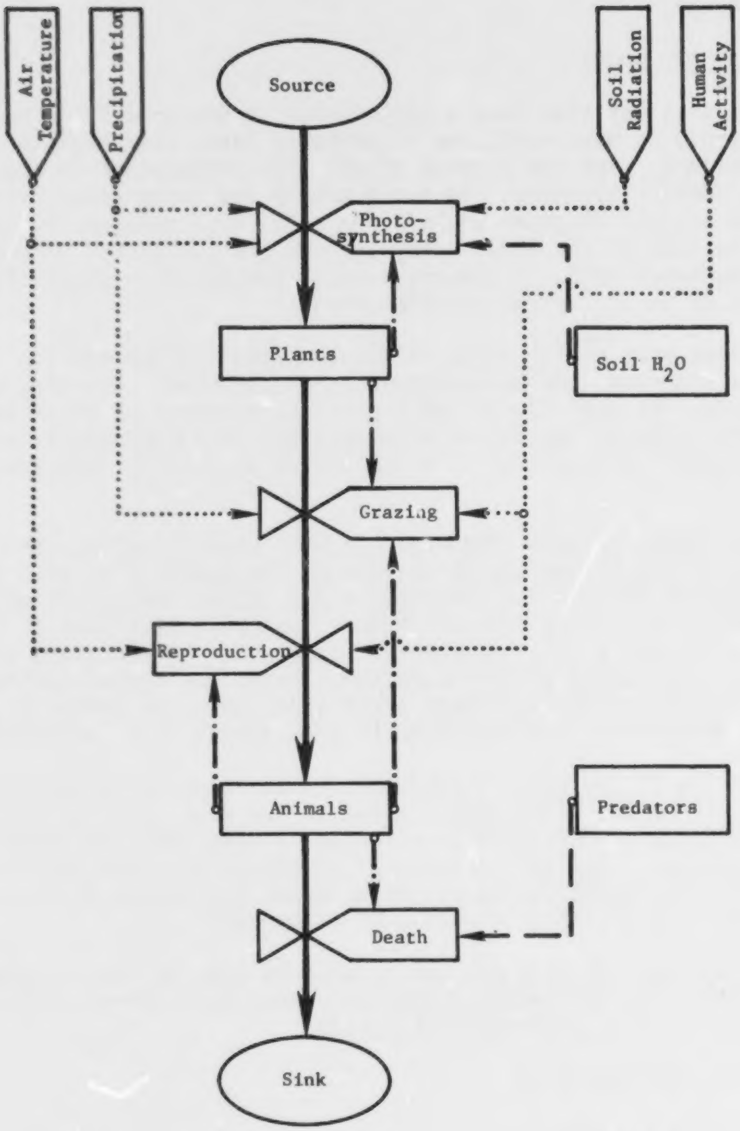

Air Temperature
Precipitation
Source
Soil Radiation
Human Activity
Photo-synthesis
Plants
Soil H_2O
Grazing
Reproduction
Animals
Predators
Death
Sink

Figure 4-7. A generalized system control diagram depicting a simplified example of carbon flow between plants and herbivores. Symbols are the same as Figure 4-6, except for the "valve" symbol (▷◁▭) representing a process. Three types of arrows depict information flows from driving variables (o·····►), internal state variables (o-·-·►), and state variables from other subsystems (o----►).

Section 4.6.2 shows how to link components and processes of different subsystems by both material flows and information flows into a large system control diagram.

4.1.4 Using the Model

Though this may seem like a lot of work to design a field baseline study, it is certainly no more work, and is probably less, than engineers must do to plan the project. And the purpose of all this preparation is the same as the engineers' careful planning: to avoid costly and irreparable mistakes later on. *System control diagrams and all the steps that precede them force the ecologist to look at the total ecosystem and its functional components carefully and systematically to determine which components and attributes should be measured in an ecological baseline study.*

The three most useful parts of the conceptual model are the impact matrix, the process diagrams, and the system control diagrams. Starting with the impact matrix. the user identifies a particular impact as it affects a process or component. The documentation accompanying the impact matrix will describe explicitly what the impact will be and how it will affect the process or component.

If the impact is on a component, it will usually affect the component directly by either increasing or decreasing the quantity of that component. This information then is used to consult the system control diagram and infer qualitatively what effect changes in that component will have on all the processes affected by that component. Changes in the processes will, in turn, affect other components of the ecosystem. Using the system control diagram, the investigator can qualitatively trace each impact on components throughout the system to estimate indirect impacts that result from the direct impact.

Similarly, if the initial impact is on an ecosystem process, the investigator can go to the process diagram to see what other things affect that process. Often a process will be affected by more than one impact through different avenues. Indirect effects of an impact on a process can be traced conceptually throughout the ecosystem by using the system diagram as described above for tracing an impact directly on a component.

Thus, the conceptual model can be used to examine, very systematically, the short- and long-term effects and the direct and indirect effects of development activities on an environmental system.

4.2 IDENTIFY PERTURBATIONS

4.2.1 The Activity Matrix

As a first step in identifying perturbations, construct an activity matrix from the list of activities in the information base. List the major development activities across the top and their associated subactivities down the side. Place a check, an "X", or some other symbol, in the cells of the matrix wherever a subactivity occurs within a major activity. Use verbs to describe activities.

An example of an activity matrix generated for an oil shale development project is presented in Figure 4-8. This two-dimensional checklist allows the investigator to review all the possible sources of perturbations systematically so that none is overlooked. Note in the example that some activities may be considered either major activities or subactivities. The reason for this is that each generates its own associated detailed list of subactivities, but each is also associated with one or more major activities. The list of subactivities, which is much more detailed in terms of what is specifically done, will be used in the perturbation matrix.

4.2.2 The Perturbation Matrix

Develop the perturbation matrix by listing the subactivities from the activity matrix across the top. Many activities result in some sort of structure, which itself produces perturbations simply by being there. For this reason, major structures resulting from the project should be listed across the top of the perturbation matrix along with the subactivities.

Next, from the list of potential environmental perturbations in the information base, choose those that are associated directly with the subactivities and structures at the top of the matrix. List all relevant perturbations along the left side of the matrix. Sometimes it is useful to generate a preliminary list, then regroup perturbations into broad categories before inserting them into the matrix. This was done in Figure 4-9. In this particular case, the perturbations fell into six different categories: meteorological, hydrological, topographic, edaphic, geological, and biological. Each situation is unique, however, and these categories might not be suitable for another type of project.

To complete the perturbation matrix, use a check, an "X", or some other symbol to identify perturbations associated with each subactivity and structure. Document this step by using forms explained in Section 4.2.3. In the example (Figure 4-9), a second symbol appears occasionally to indicate a situation where elements of the matrix can be considered either as subactivities or as perturbations. This should occur only rarely and should be minimized or avoided entirely to prevent undue confusion. Realistically, however, there are times when activities and perturbations are not easily classifiable. One of the main purposes of this systematic matrix approach is to force users to make these kinds of judgments and to document their opinions clearly.

Together, the two matrices allow the perturbations to be traced back directly to the major activities associated with the project. These perturbations will be used in the impact matrix described in Section 4.5.

A final bit of explanation concerning the examples (Figures 4-8 and 4-9) is in order here. A careful observer will note that two of the subactivities from the activity matrix do not appear in the perturbation matrix: store equipment/vehicles, and build/extend roads. In the first case, the perturbations generated by this subactivity are associated with the structures necessary for storage, which are included: paved surfaces and buildings. To have included this subactivity would have been superfluous.

Similarly, the activity matrix reveals that all of the details of building and extending roads are found as subactivities, which are included in the

	MAJOR ACTIVITIES										
SUB-ACTIVITIES THAT PRODUCE ENVIRONMENTAL PERTURBATIONS	Build/Extend Roads	Build Impoundments	Sink Shafts	Mine	Construct Underground Facilities	Construct Surface Facilities	Process Raw Materials/Operate	Build Power Transmission Lines	Build Staging Area (off-tract)	Build Pipeline(s) (off-tract)	Build Commercial Facilities
Remove Vegetation	x	x	x			x		x	x	x	x
Store Equipment/Vehicles	x	x	x		x	x			x	x	x
Operate Equipment	x	x	x	x	x	x	x	x	x	x	x
Drill & Blast	x	x	x	x	x	x	x	x	x	x	x
Grade (Excavate & Fill)	x	x			x	x		x	x	x	x
Dispose of Waste	x	x	x	x	x	x	x		x	x	x
Pave or Surface	x	x				x			x		x
Fence	x	x	x			x			x		x
Increase Traffic	x					x			x		x
Disturb Vegetation	x	x	x			x		x	x	x	x
Build/Extend Roads		*	*			*		*	*	*	*
Remove Underground Water (dewater)			x	x	x		x				x
Dispose of Water			x	x	x		x				x
Sink Shafts				*							
Build Conveyor				x							
Operate Conveyor				x			x				
Crush Mined Shale				x			x				
Erect Structures					x	x		x	x		x
Exhaust Retorting Gasses							x				

[*] Road building or sinking shafts can be considered either major activities or subactivities.

Figure 4-8. Example of an activity matrix produced for oil shale development (C-b Shale Oil Venture 1977).

		SUBACTIVITIES																	
	ACTIVE ENVIRONMENTAL PERTURBATIONS	DISTURB VEGETATION	REMOVE VEGETATION	OPERATE EQUIPMENT	DRILL AND BLAST	EXCAVATE AND FILL (GRADE)	DISPOSE OF SOLID WASTE	PAVE OR SURFACE	FENCE	INCREASE TRAFFIC	REMOVE UNDERGROUND WATER	DISPOSE OF PROCESS AND MINE DEWATERING WATER	SINK SHAFTS	BUILD CONVEYOR	OPERATE CONVEYOR	CRUSH MINED SHALE	ERECT STRUCTURES (BUILDINGS)	EXHAUST RETORTING GASES	
	CREATE FUGITIVE DUST	●	●	●	●	●	●	●	●	●			●	●	●	●			
	CREATE ODORS			●						●		●						●	
	CREATE NOISE AND VIBRATION			●	●		●			●				●	●	●	●		
METEOROLOGICAL	EMIT STEAM																	●	
	CREATE WATER VAPOR																		
	CREATE ICING																	●	
	CREATE FOG																	●	
	EMIT PARTICULATES AND AEROSOLS				●					●						●		●	
	EMIT SO_2																	●	
	EMIT H_2S																	●	
	EMIT NO																	●	
	EMIT NO_2																	●	
	EMIT NO_x			●						●								●	
	EMIT CO			●						●								●	
	EMIT CH_4																	●	
	EMIT NMHC (non-methane hydrocarbons)																	●	
	EMIT THC (total hydrocarbons)			●						●								●	
	EMIT OZONE AND OTHER OXIDANTS																	●	
	EMIT ARSENIC																	●	
	EMIT MERCURY																	●	
	EMIT SELENIUM																	●	
HYDROLOGICAL	ALTER SURFACE RUNOFF	●	●			●		●				●					●		
	ALTER PEAK FLOWS (flash flooding)	●	●			●		●									●		
	ALTER SEDIMENTATION	●	●			●						●							
	ALTER EVAPORATION											●							
	ALTER SEEPAGE					●						●							
	ALTER WATER TABLE LEVELS					●					●	●	●						
	ALTER DOWNSTREAM FLOW	●	●			●		●			●	●					●		
	ALTER STREAM CHANNELS					●					●								
	ALTER SURFACE CHEMICAL COMPOSITION						●				●	●						●	
	ALTER GROUNDWATER CHEMICAL COMPOSITION						●				●	●							
	ALTER GROUNDWATER FLOW SYSTEMS				●	●					●		●						
TOPOGRAPHIC	CREATE LANDSLIDES	●	●		●	●		●					●						
	ALTER CONTOUR OF LAND					●		●											
	ALTER SURFACE DRAINAGE PATTERNS					●							●						
EDAPHIC	CREATE COMPACTION			●		●		●		●				●			●		
	CREATE EROSION	●	●	●		●	●					●		●			●		
	REMOVE ALL VEGETATION		■			●													
	ALTER HUMUS CONTENT	●	●	●		●	●												
	MIX SOIL PROFILE				●	●	●												
GEOLOGIC	CAUSE GROUND TO SUBSIDE				●	●							●						
	EXPOSE SHRINK/SWELL CLAYS				●	●													
BIOLOGICAL	DISTURB VEGETATION	■		●															
	INCREASE ROAD KILLS																		

		STRUCTURES									
	ACTIVE ENVIRONMENTAL PERTURBATIONS	SHAFTS	ROADS AND PAVED SURFACES	UNPAVED ROADS	FENCES, CULVERTS, & OTHER BARRIERS	IMPOUNDMENTS	TRANSMISSION LINES	PIPELINES	BUILDINGS	UNDERGROUND MINES	LAND FILLS
	CREATE FUGITIVE DUST			●							●
	CREATE ODORS										●
	CREATE NOISE AND VIBRATION										
METEOROLOGICAL	EMIT STEAM										
	CREATE WATER VAPOR										
	CREATE ICING										
	CREATE FOG										
	EMIT PARTICULATES AND AEROSOLS										
	EMIT SO_2										
	EMIT H_2S										
	EMIT NO										
	EMIT NO_2										
	EMIT NO_x										
	EMIT CO										
	EMIT CH_4										
	EMIT NMHC (non-methane hydrocarbons)										
	EMIT THC (total hydrocarbons)										
	EMIT OZONE AND OTHER OXIDANTS										
	EMIT ARSENIC										
	EMIT MERCURY										
	EMIT SELENIUM										
HYDROLOGICAL	ALTER SURFACE RUNOFF		●	●	●				●		●
	ALTER PEAK FLOWS (flash flooding)		●	●					●		●
	ALTER SEDIMENTATION			●							●
	ALTER EVAPORATION		●			●			●		
	ALTER SEEPAGE					●					
	ALTER WATER TABLE LEVELS		●			●				●	
	ALTER DOWNSTREAM FLOW		●	●					●		●
	ALTER STREAM CHANNELS										
	ALTER SURFACE CHEMICAL COMPOSITION										●
	ALTER GROUNDWATER CHEMICAL COMPOSITION										●
	ALTER GROUNDWATER FLOW SYSTEMS	●								●	
TOPOGRAPHIC	CREATE LANDSLIDES		●	●						●	●
	ALTER CONTOUR OF LAND		●	●							●
	ALTER SURFACE DRAINAGE PATTERNS	●								●	●
EDAPHIC	CREATE COMPACTION										
	CREATE EROSION			●							●
	REMOVE ALL VEGETATION										
	ALTER HUMUS CONTENT										
	MIX SOIL PROFILE										
GEOLOGIC	CAUSE GROUND TO SUBSIDE	●								●	
	EXPOSE SHRINK/SWELL CLAYS	●								●	
BIOLOGICAL	DISTURB VEGETATION										
	INCREASE ROAD KILLS		●	●							

● These perturbations are identified as being associated with the corresponding activities and structures.

■ These can be considered either subactivities or perturbations

Figure 4-9. Example of a perturbation matrix: environmental perturbations generated by associated oil shale development subactivities (C-b Shale Oil Venture 1977).

perturbation matrix. To avoid redundancy, building and extending roads as a subactivity was left out.

Figure 4-10, a second example of a perturbation matrix, lists activities and perturbations for a hypothetical energy development project. This matrix, which is found at the end of the manual, is the size normally used by a project team to identify perturbations. Note that activities overlap, and that they are presented at different levels of resolution. It is usually better to list all activities at the same level of resolution to avoid redundancy. That level should be the most detailed level consistent with other constraints of the project.

4.2.3 Documentation

Table 4-3 is a standardized form for documenting the perturbations produced by each subactivity and structure. The form provides space for describing the activity or structure, its temporal characteristics, and the perturbations that it may generate. The following format is used:

(1) Activity or Structure: Identifies the factor being evaluated. This comes from the activity matrix.

(2) Date: Date of evaluation.

(3) Location: Where will the activity occur? Include the major topographic reference points and vegetative types in which the activity occurs.

(4) Time Frame and Duration: When will the activity occur, and how long will it last? Refer to the major phases of development (e.g., planning, construction, operation).

(5) Extent or Scope: What is the extent of the activity? Include specific units of measure.

(6) Perturbation: Describe each perturbation caused by the activity. Indicate the magnitude and duration of the perturbation.

Table 4-4 provides an example of how this form would be completed for the disposal of overburden in a pinyon-juniper gulch.

4.3 IDENTIFY IMPORTANT COMPONENTS

4.3.1 Specify Structural Levels of Resolution

Choose the level or levels of organization to be utilized in the study. The level selected will determine the level of resolution of any portion of the study.

For example, at a very low level of resolution, we might consider only herbivores and carnivores as heterotrophic components of an ecosystem. To introduce a higher level of resolution to the study, carnivores, ungulates, medium-sized herbivores, small herbivores, and insects might be designated as components. An even higher level of resolution would be attained by designating key species in the study area as the components to be evaluated. Table 3-6

Table 4-3 Standardized form for describing project development activities. (This form is used in describing the location, extent or scope, and time frame or duration of each project activity along with the expected magnitude and duration of each perturbation caused by the activity.)

ACTIVITY OR STRUCTURE:______________________________DATE:__________________

LOCATION:____

____

____

TIME FRAME AND DURATION:____

____

____

EXTENT OR SCOPE:____

____

____

PERTURBATION:____

____

____

PERTURBATION:____

____

____

PERTURBATION:____

____

____

PERTURBATION:____

____

____

PERTURBATION:____

____

Example

Table 4-4 Standardized form for describing project development activities. (This form is used in describing the location, extent or scope, and time frame or duration of each project activity along with the expected magnitude and duration of each perturbation caused by the activity.)

ACTIVITY: By-Product Disposal (overburden) DATE: -----

LOCATION: Overburden will be trucked from pit to Dead-Horse Gulch, ½ mile away. Major vegetation type is Pinyon-Juniper Woodland

TIME FRAME AND DURATION: Begin August 1979 and continue for 5 years.

EXTENT OR SCOPE: Fill Dead Horse Gulch to 6800 ft. elevation. Total tonnage of 65 million tons of material at rate of 13 million tons per year. Approximately 400 acres of land are involved.

PERTURBATION: Topography Modification: Permanent elimination of Dead Horse Gulch. Creation of 400 acre level plain.

PERTURBATION: Change in Natural Physical Shelters: Several rock piles within the gulch and the gulch itself will be permanently lost. Mitigation plans call for creation of brush and rock piles in post-operation.

PERTURBATION: Vegetation removal: Long term loss of 400 acres of Pinyon-Juniper. Revegetation will occur using native grasses, forbs, shrubs. Probably development of sagebrush steppe.

PERTURBATION: Change in Surface Runoff: Until revegetation is complete, increased runoff is probable. Some runoff will continue to follow Dead Horse periphery. Most will be diverted to Burro Gulch. Increased hazard for flooding, severe erosion.

PERTURBATION: Erosion: Potentially serious perturbation. Both wind and water erosion likely. Mitigation measures call for watering, placement of plastic matting prior to vegetation efforts. Benching will be practiced at toe of pile. Catchment dam will be built at lower end of gulch.

PERTURBATION: Leaching: Ground water contamination by highly saline materials is possible. Disposal area will be compacted to reduce leaching potential. Magnitude of perturbation is hard to predict.

PERTURBATION: Fugitive Dust: High winds in area will result in fugitive dust with consequent degredation of air quality, success of erosion control efforts will determine both the magnitude and duration of this perturbation.

lists components at several levels of resolution: species functional group, life form, and species group. One or more of these levels must be selected for the conceptual model.

Determine the level or levels of resolution by using sound ecological judgment to review the information base and aggregate the various components into structural elements of the specific ecosystem being studied. You may later reconsider these hierarchies of ecosystem components when components are coupled in diagrams showing the flows of matter and energy in a conceptual model of the ecosystem. An example of how to aggregate components by using different levels of resolution is developed in Section 4.3.4.

4.3.2 Temporal Definitions

Use the time horizon for the development project to establish a general sampling schedule that takes into account seasonal influences on the system. Natural seasonal variations will determine the sampling frequencies, duration, and intensities to be used for many of the system measurements. Refine this schedule later to address the seasonal changes as you select the actual components and attributes to be measured.

As an example, Figure 4-11 shows the seasonal changes in numbers of aquatic vertebrates in a Colorado stream. Preliminary information of this type is extremely useful in establishing field sampling schedules, and often it is available from the scientific literature or one of the other information sources.

4.3.3 Identify Ecological Response Units

In selecting an ecological response unit (ERU), consider the following fundamental features of the land, (1) bedrock and surficial geology, (2) topography and geomorphology, (3) weather and climatic influences, (4) soils and (5) vegetation (Davis 1976). Since vegetation serves as an integrator of the first four features listed, and since changes in vegetation will probably be the first indication of an environmental impact, vegetation types will be used as a starting point for defining ERU's.

Although there are no fixed systems for vegetation classification, an example of one type of grouping appears in Table 4-5. As you can see, the subdivisions allow several levels of resolution to be selected. Again, the level of resolution selected for the ERU will depend on the scope of the study, objectives, the nature of the terrain, and the variety of potential ERU's that exist in the study area.

An example of how ERU's can be selected is presented in Table 4-6. The 13 original vegetative community types occurring on major topographic features of an oil shale development site were grouped into six ecosystem response units. The level of resolution is moderate, but was considered adequate for the objectives of that study. Note the slight changes from the preliminary classification of Table 3-6.

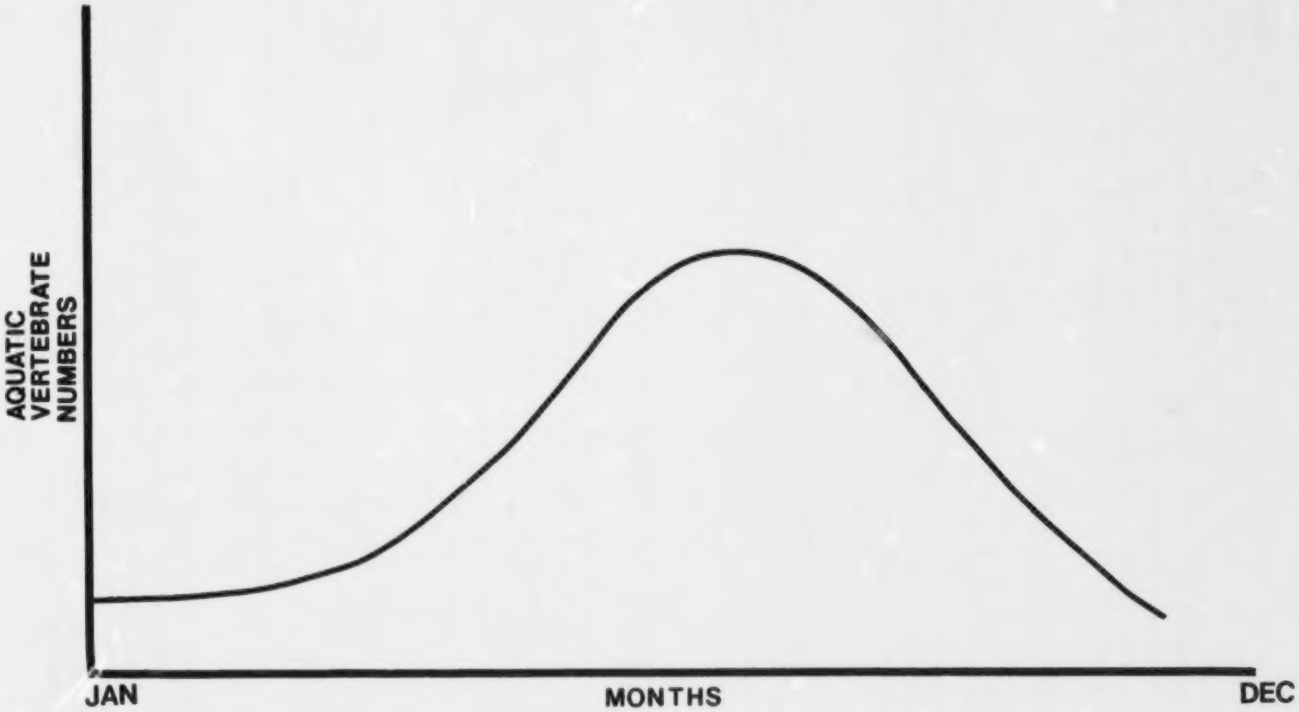


Figure 4-11. An example of seasonal fluctuations of aquatic invertebrate numbers in a western Colorado stream (C-b Shale Oil Venture 1977).

Table 4-5. Examples of classifying land into ecological response units based on vegetative and other characteristics. Four hierarchical levels of resolution are shown (from Davis 1976 and Smith 1974).

Ecological Response Units			
1	2	3	4
Wetlands →	Fresh	Inland Fresh Areas	Seasonally flooded basins or flats Fresh meadows Shallow fresh marshes Deep fresh marshes Open fresh water Shrub swamps Wooded swamps Bogs
		Coastal Fresh Areas	Shallow fresh marsh Deep fresh marsh Open fresh water
	Saline	Inland Saline Areas	Saline flats Saline marshes Open saline water
		Coastal Saline Areas	Salt flats Salt meadows Irregularly flooded salt marshes Regularly flooded salt marshes Sounds and bays Mangrove swamps
Grasslands & related vegetation			
Woody shrublands			
Woodlands			
Forests			
Alpine, boreal, & tundra types			

Table 4-6. Aggregations of plant communities into ecosystem response units for a conceptual model of the C-b system (C-b Shale Oil Venture 1977)

Plant Community List	Ecosystem Response Units
Pinyon-juniper	Upland forest
Chained rangeland Bunchgrass Sagebrush Mountain shrub	General upland
Rabbitbrush Greasewood Sagebrush Wildrye Riparian	General Bottomland
Meadow	Meadow
Stream	Stream
Pond/marsh	Pond

4.3.4 Specify Ecosystem Components

Selecting workable components often is a repetitive task. Sometimes several different arrangements of components are tried until the arrangement best-suited to the specific site and the objectives of the study is found.

First, group the lists of flora and fauna from the information base according to the specified ERU's in which they are found. This links them with spatial units. Table 3-6 is an example of how this can be done with species lists.

Next identify important structural components of the ecosystem. If the information base has been organized as in Table 3-6, identifying structural components according to their life forms or functional roles is relatively easy. Animal species can be grouped into trophic levels (herbivores, omnivores, and carnivores) or different broad taxonomic groupings (small mammals, medium mammals, birds, rodents, arthropods, etc.). Sometimes special economic or aesthetic significance associated with a species requires that the species be treated separately (cattle, deer, etc.).

Consider abiotic components also, for often these are the media that transport airborne or waterborne environmental perturbations to the biota. Air, soil, and water are all components of the ecosystem, and they can be subdivided in various ways. In arid regions, for instance, the water table and different soil horizons might be extremely sensitive to moisture changes brought about by development activities. Different soil layers, therefore, might be designated separate components. Meteorological, hydrological, edaphic, and geologic factors must all be considered in developing the component list.

An example of an initial list of components generated for a baseline study on an oil shale tract in western Colorado is shown in Table 4-7. The 56 components have been both aggregated and disaggregated from the earlier lists: Plants are grouped into life forms, but in some cases their functional parts have been disaggregated into subcategories of shoots, roots, standing dead, etc. This is a fairly high level of resolution. It was later modified to allow a more workable conceptual model to be built, as discussed in Section 4.4.2.

In summary, you must apply certain criteria for selecting levels of resolution, life forms, growth forms, functional groups, or species. These criteria are determined by the objectives of the study, the specific site characteristics, the legal requirements, and the socioeconomic considerations established in earlier steps of the baseline study. Sound biological judgment is also essential in selecting components.

4.4 IDENTIFY IMPORTANT PROCESSES

4.4.1 Select Flow Currencies

Choose the flow currencies for the model on the basis of conceptual simplicity and ease of measurement. Water, heat, or soil nutrients, such as phosphorus, nitrogen, and potassium, are frequently used as currencies. Conceptual currencies such as animal or plant weights or numbers may also be used.

Table 4-7. Example list of ecosystem components with attributes. (C-b Shale Oil Venture 1977)

Ecosystem Components
Cattle Numbers
Deer Numbers
Insectivorous Bird Numbers
Omnivorous Bird Numbers
Carnivorous Bird Numbers
Coyote and Bobcat Numbers
Rabbit Numbers
Rodent Numbers
Reptile Numbers
Arthropod Numbers
Individual Cattle Weights
Individual Deer Weights
Individual Insectivorous Bird Weights
Individual Omnivorous Bird Weights
Individual Carnivorous Bird Weights
Individual Coyote and Bobcat Weights
Individual Rabbit Weights
Individual Rodent Weights
Individual Reptile Weights
Individual Arthropod Weights
Live Shoots Annual
Live Shoots Perennial Grass
Live Shoots Perennial Forb
Live Shoots Shrub
Live Shoots Tree
Standing Dead Annual
Standing Dead Perennial Grass
Standing Dead Perennial Forb
Standing Dead Shrub
Standing Dead Tree
Live Roots Annual
Live Roots Perennial Grass
Live Roots Perennial Forb
Live Roots Shrub
Live Roots Tree
Aboveground Litter
Belowground Litter
Upper Soil Layer Temperature
Lower Soil Layer Temperature
Surface Water (Snow)
Upper Soil Layer Water
Lower Soil Layer Water
Ground Water
Terrestrial Land Areas
Aquatic Vertebrate Numbers
Aquatic Invertebrate Numbers
Individual Vertebrate Weights
Individual Invertebrate Weights
Rooted Biomass Plants
Non rooted Biomass Plants
Detritus Biomass
Upper Water Layer (Ice) Temperature
Lower Water Layer (Water) Temperature
Upper Water Layer Volume
Lower Water Layer Volume
Surface Area of Aquatic Types

Choose currencies according to the following criteria:

1. What components are to be linked?
2. How common is a specific currency to these components?
3. How easy is the currency to measure in the ecosystem?

Five flow currencies were used in the oil shale model (C-b Shale Oil Venture 1977): animal numbers, animal weights, carbon, heat, and water.

4.4.2 Draw Flow Diagrams

Drawing a flow diagram begins with a flow matrix (Figure 4-3). List ecosystem components across the top and down the side in the same order. To provide conceptual clarity, add sources and sinks; they account for the transfer of flow currency into and out of the ecosystem under study. Place a symbol in each cell where currency flows from the component at the left (the row component) into the component at the top (the column component).

In the oil shale example it was quickly evident that 56 components at a high level of resolution were too many to deal with in a conceptual model for that study. Those components then were further aggregated into 24 components of lower resolution, plus 10 sources and sinks (Table 4-8). Because most of the same components at this coarse a level of resolution were found in either terrestrial or aquatic habitats, there was no need, at this level, to subdivide further into ERU's. Therefore, only two flow matrices were constructed, one for a general terrestrial ecosystem and one for a general aquatic ecosystem on the oil shale site (Figures 4-12 and 4-13). All five flow currencies are represented in each matrix. However, in some cases, if the ERU's are sufficiently different, or if flow currencies differ, it may be necessary to construct a flow matrix for each ERU.

Draw the flow diagrams from the flow matrices, using boxes and arrows (e.g., Figures 4-2, 4-4, and 4-5). Another example using some of the oil shale components is shown in Figure 4-14. The flow currency subsystems depicted in the flow diagrams will eventually be linked together into a conceptual model of the ecosystem (Section 4.6.2).

4.4.3 Identify Processes

For each arrow in the flow diagram, at least one physical, chemical, or biological process controls the flow depicted by the arrow. The next step in developing the conceptual model is to identify important processes controlling the flows throughout the ecosystem. Go through the diagram systematically using sound ecological judgment. Ideally, the entire team should be involved, because no one individual will have enough in-depth knowledge about all the physical, chemical, and biological processes involved to select important processes. Table 4-2 presents one example list of processes, and the oil shale study provides another (Table 4-9). The processes controlling flows in the carbon, heat, and water subsystems can be related directly to the flow matrix (Figure 4-12) and the flow diagrams (Figure 4-14).

Table 4-8. Example list of aggregated components in their respective flow currency subsystems. (C-b Shale Oil Venture 1977)

Flow Currency Subsystem	Aggregated Components
Animal Numbers	Source Terrestrial animal numbers Aquatic vertebrate numbers Aquatic invertebrate numbers Sink
Animal Weights	Source Terrestrial animal weights Aquatic vertebrate weights Aquatic invertebrate weights Sink
Carbon	Source Live shoots Live roots Standing dead Aboveground litter Belowground litter Aquatic rooted plants Aquatic nonrooted plants Aquatic detritus Sink
Heat	Source Soil top layer heat Soil bottom layer heat Aquatic top layer heat Aquatic bottom layer heat Sink
Water	Source Surface water (snow, ice, rain) Top soil water Bottom soil water Ground water layer Aquatic ice layer water Aquatic water Sink

TO FROM	population source	animal numbers	population sink	animal weight source	animal weights	animal weight sink	carbon source	live shoots	live roots	standing dead	above ground litter	below ground litter	carbon sink	heat source	top layer heat	bottom layer heat	heat sink	water source	surface water	top soil water	bottom soil water	groundwater layer	water sink
population source		X																					
animal numbers			X																				
population sink																							
animal weight source					X																		
animal weights						X																	
animal weight sink																							
carbon source								X			X												
live shoots									X	X	X		X										
live roots								X				X	X										
standing dead											X		X										
above ground litter													X										
below ground litter													X										
carbon sink																							
heat source															X								
top layer heat																X	X						
bottom layer heat															X		X						
heat sink																							
water source																			X				
surface water																				X			X
top soil water																					X		X
bottom soil water																						X	X
ground water layer																							X
water sink																							

Figure 4-12. A coupling matrix for flows within terrestrial ecosystem response units for animal populations and weights, carbon biomass, heat, and water. "X's" represent flows from components at left into components across top (C-b Shale Oil Venture 1977).

TO FROM	population source	vertebrate animals	invertebrate animals	population sink	animal weight source	vertebrate weights	invertebrate weights	animal weight sink	carbon source	rooted plant biomass	nonrooted plant biomass	detritus	carbon sink	heat source	top layer heat	bottom layer heat	heat sink	water source	surface water	water	water sink
population source		X	X																		
vertebrate animals				X																	
invertebrate animals				X																	
population sink																					
animal weight source						X	X														
vertebrate weights								X													
invertebrate weights								X													
animal weight sink																					
carbon source										X	X	X									
rooted plant biomass												X	X								
nonrooted plant biomass												X	X								
detritus													X								
carbon sink																					
heat source															X						
top layer heat																X	X				
bottom layer heat															X		X				
water source																			X		
surface layer																				X	X
water																					X
water sink																					

Figure 4-13. A coupling matrix for flows within aquatic ecosystem response units for animal populations and weights, carbon biomass, heat, and water. "X's" represent flows from components at left into components across top (C-b Shale Oil Venture 1977).

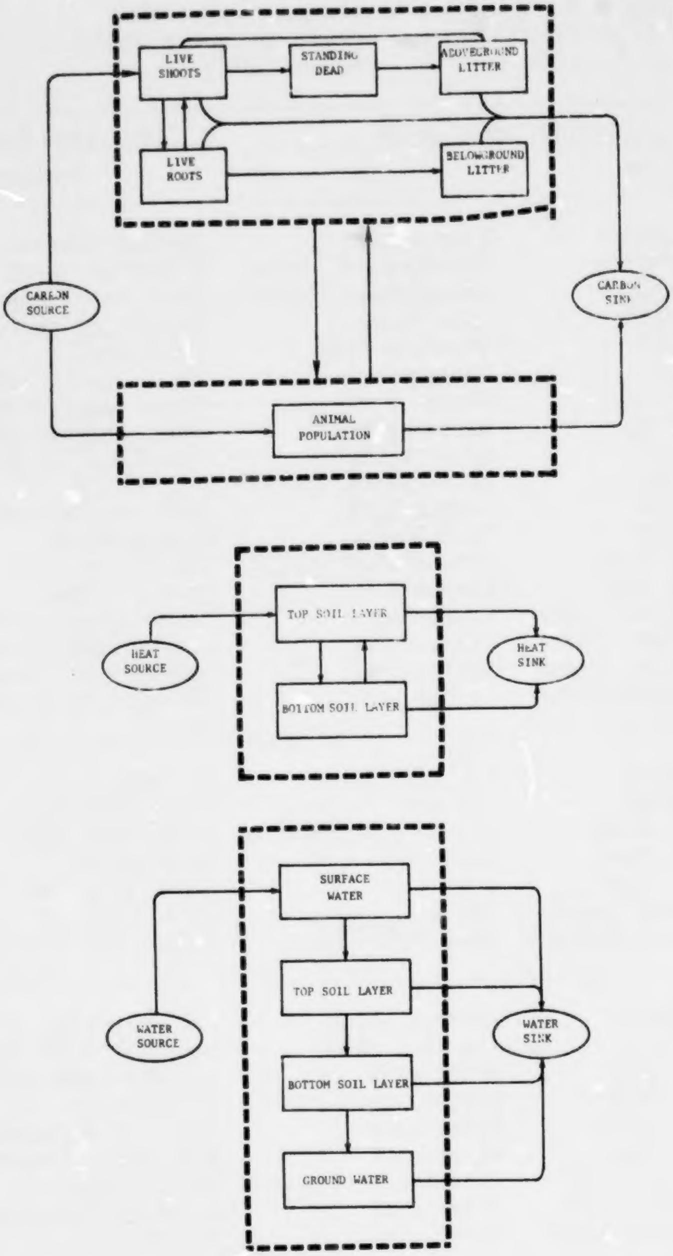

LIVE SHOOTS
STANDING DEAD
ABOVEGROUND LITTER
LIVE ROOTS
BELOWGROUND LITTER
CARBON SOURCE
CARBON SINK
ANIMAL POPULATION
HEAT SOURCE
TOP SOIL LAYER
HEAT SINK
BOTTOM SOIL LAYER
SURFACE WATER
WATER SOURCE
TOP SOIL LAYER
WATER SINK
BOTTOM SOIL LAYER
GROUND WATER

Figure 4-14. Diagrams of carbon, heat, and water flow currency subsystems on an oil shale tract in Colorado (C-b Shale Oil Venture 1977).

Table 4-9. Examples of ecosystem processes
used in an oil shale development conceptual model.
(C-b Shale Oil Venture 1977)

Flow	Ecosystem Components		Ecosystem Processes
Currency	From	To	Process
CARBON	Carbon source	Live shoots	Phytosynthesis
	Carbon source	Aboveground litter	Excretion input
	Carbon source	Aboveground litter	Dead animal input
	Live shoots	Live roots	Translocation to roots
	Live shoots	Standing dead	Shoot death
	Live shoots	Aboveground litter	Shoot shattering
	Live shoots	Carbon sink	Shoot respiration
	Live shoots	Carbon sink	Shoot grazing output
	Live roots	Live shoots	Translocation to shoots
	Live roots	Belowground litter	Root death
	Live roots	Carbon sink	Root respiration
	Live roots	Carbon sink	Root grazing
	Standing dead	Aboveground litter	Dead shattering
	Standing dead	Carbon sink	Dead grazing
	Aboveground litter	Carbon sink	Aboveground decomposition
	Aboveground litter	Carbon sink	Aboveground litter grazing
	Belowground litter	Carbon sink	Belowground litter grazing
	Belowground litter	Carbon sink	Belowground litter grazing
HEAT	Heat source	Top soil layer	Radiation
	Heat source	Top soil layer	Convection in
	Top soil layer	Bottom soil layer	Conduction down
	Top soil layer	Heat sink	Reradiation
	Top soil layer	Heat sink	Convection out
	Bottom soil layer	Top soil layer	Conduction up
	Bottom soil layer	Heat sink	Conduction down
WATER	Water source	Surface water	Precipitation
	Surface water	Top soil water	Snow melt/infiltration
	Surface water	Water sink	Surface evaporation
	Top soil water	Bottom soil water	Percolation
	Top soil water	Water sink	Top soil evaporation
	Top soil water	Water sink	Upper soil transpiration
	Bottom soil water	Ground water layer	Percolation
	Bottom soil water	Water sink	Lower soil transpiration
	Ground water layer	Water sink	Springflow

Define processes clearly by using a group of words to specify a process, e.g., plant shoot growth, aquatic nonrooted plant photosynthesis, and aquatic radiation in. These processes will constitute a major part of the impact matrix.

4.5 DEVELOP AN IMPACT MATRIX

An impact matrix draws together and uses the information from earlier steps. Construct the impact matrix by listing the environmental perturbations identified in Section 4.2 across the top. List components and processes identified in Sections 4.3 and 4.4 down the left side.

Figures 4-15 and 4-16, located in the back of the manual, illustrate one way of constructing an impact matrix. These figures use the perturbations list from Figure 4-10 to produce example impact matrices for general terrestrial and aquatic ecosystems. The components are highly aggregated in this example, and the processes are less specific than in the oil shale example (Figure 4-17).

Figure 4-17 presents only a partial listing of the impact matrix from an oil shale study (C-b Shale Oil Venture 1977) because of size constraints. (The original matrix is 79 x 70.) The numerical rankings used to identify each impact are explained in Section 4.5.2.

4.5.1 Use of the Impact Matrix

You can use the impact matrix to identify where impacts will occur and to estimate the relative magnitude and importance of individual perturbations on ecosystem components and processes.

The following items must be considered in determining the magnitude and importance of a perturbation or effect.

1. Magnitude of the perturbation: What is the spatial extent and intensity of the perturbation, and how long will the perturbations be present? This type of information has already been documented by using the form in Table 4-3.

2. Magnitude of the effects: What will be the extent of the effects on the component or process? Perturbations may set off a "chain reaction" of effects: first-order, second-order, and higher-order. First-order effects result directly from a perturbation. Second-order effects emanate from first-order, and so on. Consider all effects that will influence the ranking process.

3. Persistence of the effects: How long will it take the natural system to recover from the disturbance? Short-term effects often have little impact on system dynamics, or they can be assimilated quite readily by the system. Long-term effects are generally more serious than short-term effects. They usually are detected at the population, community, or ecosystem level of organization, and they usually modify a system's functional or structural properties.

		PERTURBATIONS - TERRESTRIAL														PERTURBATIONS - ATMOSPHERIC						
		SULFUR EMISSIONS	NITROGEN EMISSIONS	OZONE AND OXIDANT EMISSIONS	FLUORIDE EMISSIONS	CO EMISSIONS	HYDROCARBON EMISSIONS	PARTICULATES, AEROSOLS, AND DUSTS	TRACE ELEMENT CONTAMINANTS	FOG	ICE	STEAM EMISSIONS	ODOR	NOISE AND ACTIVITY		DISTURBED VEGETATION	UNREVEGETATED BARE AREAS	TRANSMISSION LINES AND PIPELINES	INCREASED ROAD KILLS	ROADS AND PAVED SURFACES	UNPAVED ROADS	BARRIERS (FENCES, CULVERTS, ETC.)
ABIOTIC PROCESSES	SOLAR RADIATION							2		2		1										
	HEAT CONVECTION											1				2	3			2	2	
	HEAT CONDUCTION, TERRESTRIAL										2					3	3			2	2	
	HEAT CONDUCTION, AQUATIC																					
	PRECIPITATION							2		2		1										
	EVAPORATION									3	2	1				3	3			1	1	
	MELTING							1		2		1					3			1	1	
	INFILTRATION															3	3			2	2	
	PERCOLATION																					
	RUNOFF															3	3			2	1	
	STREAMFLOW																3			1	1	
	SPRINGFLOW																			1	1	
	FLOODING																2			1	1	
	GROUNDWATER FLOW																2			1	1	
	LITTER										2					3						
	WEATHERING (GEOLOGIC)	1	1	1	1			1		2		1										
BIOTIC PROCESSES - PLANT	GERMINATION AND PHENOLOGY	1	1	1	2		1		2	1		1										
	PHOTOSYNTHESIS	3	1	2	3		1	1	2	2		1										
	PLANT RESPIRATION	3	1	2	3		1		2													
	PLANT GROWTH	3	1	2	3		1	1	3	2	3	1										
	SHOOT DEATH	2	1	1	3		1	1	2		3											
	SHOOT GRAZING																					
	SHOOT SHATTERING																					
	ROOT DEATH	1	1	1	1		1	1	2													
	ROOT GRAZING																					
	DEAD GRAZING																					
	LITTER GRAZING							1														
	DEAD SHATTERING										2											
	DEFORESTATION	2	1	1	2		1	1	2													
	REVEGETATION	2	1	1	2		1	1	3	1												
	INTERCEPTION OF PRECIPITATION															2	3			3		
	LITTER DECOMPOSITION	3	1	1	2		1	1	2	2		1										

Figure 4-17. Example of a portion of an impact matrix developed for an oil shale project (C-b Shale Oil Venture 1977).

4. The specific objectives of the baseline program: Are certain components more important than others, by human or social definition? If so, effects on these components, or on processes affecting these components, may warrant a higher ranking than would otherwise be given.

4.5.2 Ranking Impacts

Integer values, one through three, are assigned as follows:

One -	Effects occur but are of only slight concern; slightly important effects.
Two -	Effects of moderate concern; moderately important effects.
Three -	Effects are of particular concern; most important effects.
Blank -	The perturbation has no effect on the process or component.

Assign numbers using the following stepwise process:

1. Identification. Systematically scan the column under each perturbation. Identify the potential impacts of each perturbation on components and processes affected by placing a small check mark "✓" in a corner of the appropriate matrix cell.

2. Assign values to processes. A perturbation generally affects a component through its effects on a process. It is therefore necessary to evaluate the effects on processes first. In each process/perturbation cell containing a check, assign a value (1-3) corresponding to your judgment of the magnitude and importance of the impact.

3. Assign values to components. After the processes have been evaluated, assign values to the impacts on each component. The value assigned to a component should reflect the total impact of the perturbation on the component, including the effects on the processes that are most important to that component.

The values that you have assigned to each impact cell can now be summed to provide two relative measures of impacts. To obtain the total effect of all perturbations on any component or process, sum the impact rankings across the matrix. For the total effect of a single perturbation on all components and processes, sum the impact values for all components in the perturbation column. Do not include process scores from the column, since they are reflected in the assigned component values.

As an example, in Figure 4-17 each impact cell has been assigned a value according to the procedures described above.

4.5.3 Documentation

Since the evaluation of relative magnitude and importance of impacts is subjective, documentation of your procedure is important. Table 4-10 provides a standardized form for recording the assumptions made in assigning numerical

Table 4-10. Standardized form for ranking the importance of perturbation impacts on ecosystem components and processes.

Source:________________ Date:______________ Analyst:___________________

Component or Process:__________________________________

Perturbation____

____

____

____ Ranking:_________

Perturbation____

____

____

____ Ranking:_________

Perturbation____

____

____

____ Ranking:_________

Perturbation____

____

____

____ Ranking:_________

Perturbation____

____

____

____ Ranking:_________

Perturbation____

____

____

____ Ranking:_________

ranks. Fill out a separate sheet for each component or process in the matrix, and include the following information.

Source: An impact matrix.

Date: Date of evaluation.

Component or Process: The component or process being analyzed.

Perturbation: Name of each perturbation that produces an impact on the component or process. Include a brief description of the perturbation, and indicate the reasons for the numerical ranking.

Ranking: The numerical value (1-3) assigned to the cell.

Table 4-11 is an example of an impact documentation sheet which has been produced for a portion of an oil shale matrix. The table illustrates the rationale for the numerical rankings assigned to the effects on photosynthesis by the sulfur emissions, nitrogen emissions, ozone and oxidants, fluoride emissions, and hydrocarbon emissions.

4.6 DEVELOP CONTROL DIAGRAMS

4.6.1 Process Diagrams

To build a process or flow-control diagram, consult the flow diagrams and list of processes prepared in Section 4.4 to determine each flow and the process affecting it. At least one (and occasionally more than one) process diagram is required for each arrow on a flow diagram.

Begin by choosing one of the arrows on a flow diagram. Each process regulating that flow will require a separate sheet of paper, but in most cases you will use only one process per flow. The symbols that are used in the process diagram are shown in Figure 4-6.

With the paper arranged horizontally, draw symbols for the two components connected by the arrow on the flow diagram. For consistency, put the donor component near the left edge of the paper and the receiver compartment near the right. Midway between them, draw the "valve" symbol for the process controlling that flow (see Figure 4-6). Now connect all three symbols with a solid, one-way arrow to depict the flow from the left compartment, through the process, and into the right compartment.

Next, ask yourself, "What are the driving variables that affect this process?". Above the arrows of the process diagram, draw and label a pentagon for each driving variable that influences this process. Put a circle between each variable and the process symbol.

Now we wish to know exactly how each driving variable influences the process: What characteristics, or attributes, of the variable affect the process? As you identify these attributes, list at least one in each circle associated with a driving variable. For example, if solar radiation is a driving variable that influences the process of photosynthesis, the attributes of solar radiation that might appear in the circle are light and heat.

Table 4-11. Sample of completed form for documenting information related to effects on ecosystem components and processes of perturbations from oil shale development.

Source: Impact matrix Date: ______ Analyst: ______

Component or Process: Photosynthesis

Perturbation Sulfur emissions. Assuming a worst-case situation, sulfur emissions are anticipated to be high enough to reduce plant photosynthesis. Meteorological conditions will often suppress dispersion.

Ranking: 3

Perturbation Nitrogen emissions. Assuming a worst-case situation, nitrogen emission will be high but below the concentration required to significantly affect plant processes.

Ranking: 1

Perturbation Ozone and oxidants. Elevated concentrations may result under specific meteorological conditions as a result of photochemical reaction. Will probably affect photosynthesis at certain times.

Ranking: 2

Perturbation Fluoride emissions. A highly phytotoxic air pollutant. Although released in low concentrations, it will impair plant photosynthesis.

Ranking: 3

Perturbation Hydrocarbon emissions. Generally not phytotoxic. Release of ethylene could, however, affect photosynthesis.

Ranking: 1

Perturbation ______

Ranking: ______

To this point we have identified the driving variables that affect a specific ecological process. Any man-induced perturbations to the ecosystem arising from energy-development activities should also be considered driving variables: They arise outside the system, affect it, but usually are not themselves affected by it. Make certain, then, to include in the diagrams the perturbations identified in the impact matrix. For consistency and convention, we have elected to place all the driving variables above the center of the page on the process diagram.

State variables go below the center of the page. Use rectangles to represent state variables and circles to list attributes. An example of a state variable affecting photosynthesis is soil. Attributes of soil that influence photosynthesis are soil temperature and soil moisture.

Draw a process diagram for each process that controls a flow. However, before drawing any diagram, be certain that the process is important enough to warrant its own diagram. Can it be incorporated into another, more comprehensive process without significant loss of information? Is the process too detailed or not detailed enough for the level of resolution we have specified? There is no general way to answer these questions; it will be up to the judgment of the individual investigator to decide.

Figure 4-18 is an example taken from an oil shale development baseline study. It provides a qualitative look at the natural driving variable (air), relevant oil shale development driving variables (sulfur, nitrogen, ozone, and oxidant emissions), and the state variables (upper and lower soil moisture) that affect the process of plant shoot death. The significant attributes of these ecosystem components are also specified.

4.6.2 System Control Diagrams

Use the flow diagrams and the process-control diagrams to develop the system control diagrams. Figure 4-19 provides a set of standard symbols. If the components on the flow diagrams are not widely spread out, you will need to redraw them on a large sheet of paper, allowing plenty of space between components. Connect components by solid arrows as before. On each arrow, about midway between components, draw a process (valve) symbol as illustrated in Figure 4-7. If more than one process controls a flow, space the valves fairly evenly along the arrow.

Now, using the process diagrams, draw the information linkages. Begin by drawing driving variables, both natural and man-induced, that affect each process in the subsystem. (For consistency, put them at the top of the page.) For each valve on the system control diagram, systematically work through the specific process diagram for that valve, answering the following questions:

1. What are the driving variables regulating this process?
2. What are the subsystem state variables regulating this process; i.e., what are the feedback loops within this subsystem?
3. What are the state variables from other subsystems regulating this process?

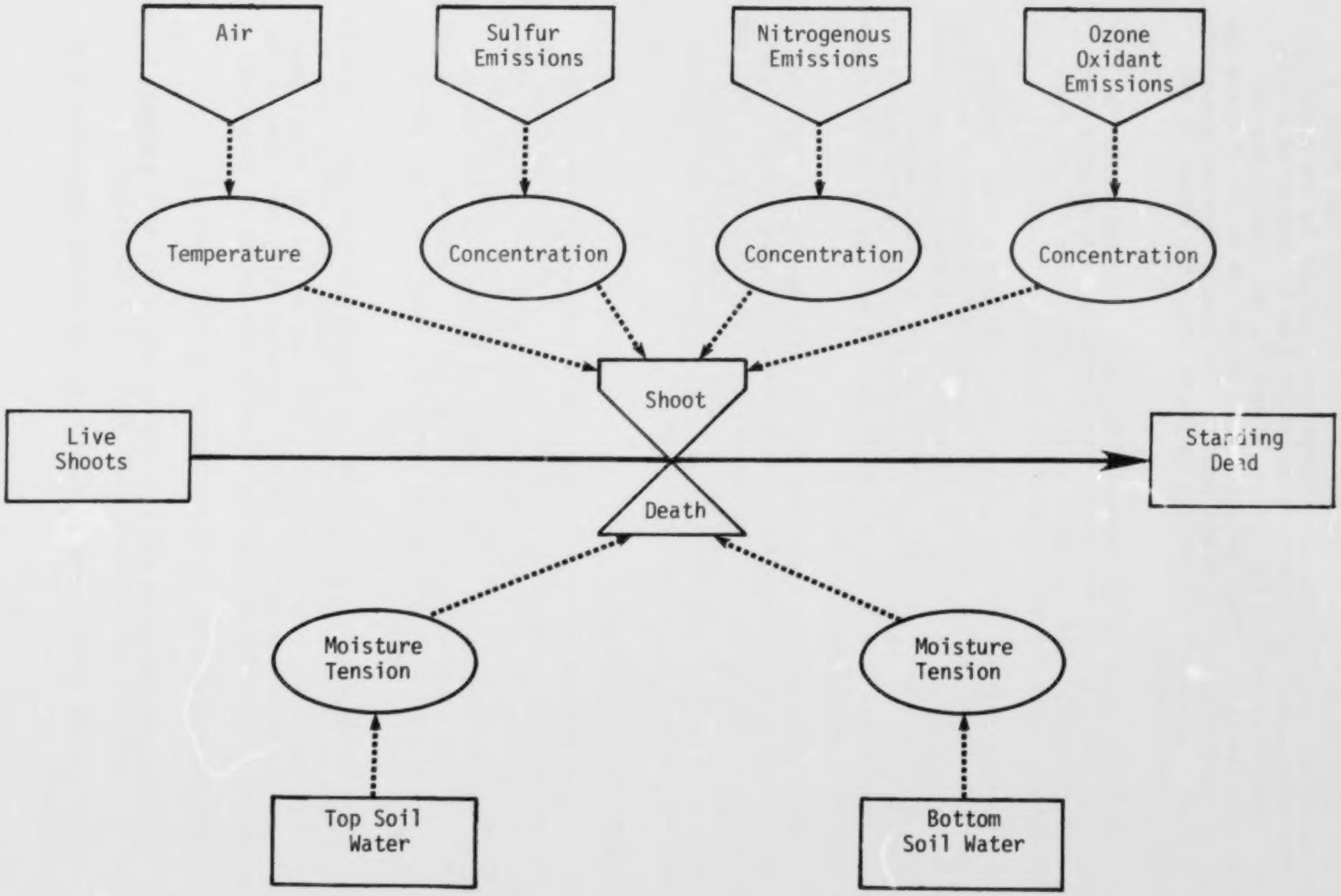
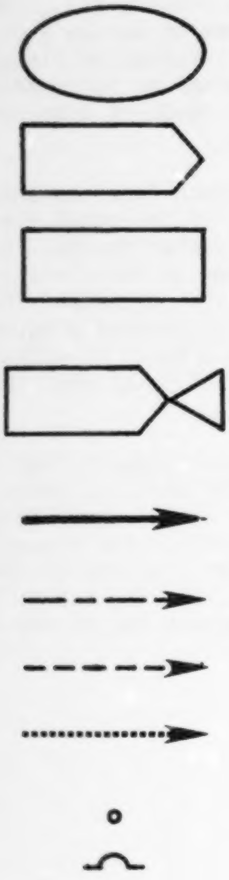

Air
Sulfur Emissions
Nitrogenous Emissions
Ozone Oxidant Emissions
Temperature
Concentration
Concentration
Concentration
Shoot
Live Shoots
Standing Dead
Death
Moisture Tension
Moisture Tension
Top Soil Water
Bottom Soil Water

Figure 4-18. A process diagram for depicting the ecosystem components and their attributes that affect the death of plant shoots. Perturbations and natural driving variables are at the top, and state variables are at the bottom (modified from C-b Shale Oil Venture 1977).



Source or sink.

Driving variable.

State variable (ecosystem component).

Process. These may be thought of as valves that control the flows of matter or energy through the subsystem.

Material or energy flow. Denoted by a solid line.

Information flows. Dots and dashes represent input from driving variables. Dashes trace the inter-subsystem influences of state variables on processes. Dots are the intra-subsystem feedback loops through which state variables influence processes within their own subsystems.

Takeoff points and crossings. The small circles represent take-off points or branches in information linkages. The other symbol simply denotes a crossover.

Figure 4-19. Symbols and conventions used in system control diagrams.

For each answer, draw an information arrow from the state or driving variable to the process valve. When state variables outside the subsystem are involved, draw and label state variable boxes at the edge of the paper to bring the information arrows into the subsystem (Figure 4-7). One refinement you might want to employ for very complex systems is to use a different form of broken arrow for each of the three types of information flows. This has been done in Figure 4-7 to identify quickly whether an information flow is from a driving variable, is part of an internal feedback loop, or is part of the feedback from the larger total system.

A system control diagram can be drawn for each flow currency subsystem on a separate sheet of paper. Sometimes, however, if the total diagrammatic model of the ecosystem is not too large, it is easier and more useful to draw all the system control diagrams for the subsystem on one sheet of paper, connecting the subsystems directly with information linkages. Although it gets very large and complex, such a master system control diagram is extremely useful, when mounted on a wall, for tracing the effects of perturbations throughout the entire system. This is much harder to do when subsystem diagrams are on separate pages.

Figure 4-20 is an example of a system control diagram from an oil shale development baseline study. Linkages between the heat subsystem and the water subsystem are clearly identified. Often such linkages occur between several subsystems. When all subsystems are linked together into a single system control diagram, the flows of information, matter, and energy can become very complex. However, with some practice, such diagrams are not difficult to read and to use in tracing anticipated impacts throughout the entire system.

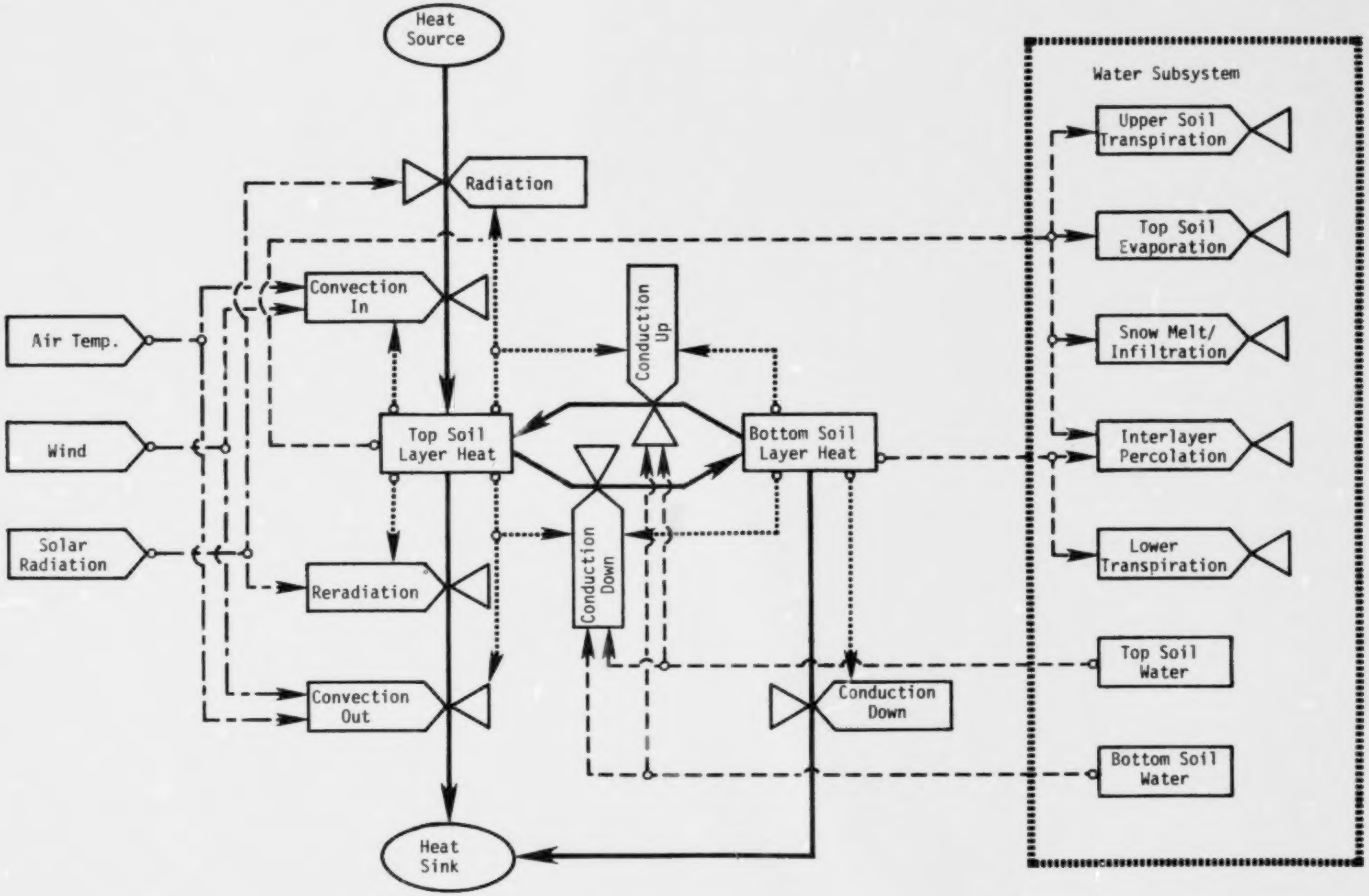

Heat Source
Radiation
Convection In
Air Temp.
Wind
Solar Radiation
Top Soil Layer Heat
Conduction Up
Conduction Down
Bottom Soil Layer Heat
Reradiation
Convection Out
Conduction Down
Heat Sink
Water Subsystem
Upper Soil Transpiration
Top Soil Evaporation
Snow Melt/ Infiltration
Interlayer Percolation
Lower Transpiration
Top Soil Water
Bottom Soil Water

Figure 4-20. Partial system control diagram of heat subsystem on an oil shale development site (modified from C-b Shale Oil Venture 1977). Symbols are explained in Figure 4-19.

5.0 SELECT ECOLOGICAL ATTRIBUTES FOR STUDY

5.1 INTRODUCTION AND OVERVIEW

In developing a holistic perspective for an ecological baseline study, we began with a comprehensive information base about the environmental system and systematically reduced that base to a workable size. Procedures of Chapter 2 were used to compile and organize socioeconomic and legal considerations important to the study. These procedures identify special cases of ecosystem components that need to be studied for social, economic, or legal reasons, components that might be missed by the narrower focus of Chapters 3 and 4.

Chapters 3 and 4 provide a systematic approach to compiling and organizing information about the environmental system per se, based on other criteria. These criteria identify ecosystem components and processes that are important, either because they are central to the structure and function of the ecosystem, or because they might be seriously impacted by the anticipated development activities.

This chapter describes how to use the materials developed earlier to determine which attributes of which ecosystem components should be studied in the field. Specific parameters that can be measured for each attribute and how they are measured are discussed in Chapter 6. Chapter 5, then, bridges the gap between the early phases of the baseline study, where existing information is compiled and organized, and the field phase, in which new data are collected about key ecosystem components and processes.

5.2 IDENTIFY ATTRIBUTES

The attribute selection process is one of review, reconsideration, and refinement: review and reconsideration of components and attributes identified in earlier steps, and refinement of the total list to a focused selection of key attributes that should be measured. The relationships between components and attributes is explained in Section 4.1.3.2. Tables 4-1 and 5-1 illustrate this relationship. In the oil shale baseline study from which Table 5-1 was modified, the field portions of the study were conducted concurrently with the development of the conceptual model. Consequently many more attributes were studied than might have been necessary, had the model been developed first and then used to design the field studies. (As it was, the model was used to design the monitoring and mitigation plans.) Nonetheless, Table 5-1 is a good

Table 5-1. General inventory of ecosystem components (state and driving variables) and the measured attribute(s) of each component (modified from C-b Shale Oil Venture 1977)

COMPONENT	ATTRIBUTE
Air	Barometric pressure Temperature Relative humidity Potential evaporation Trace elements Short-term CO_2 levels Short-term particulate levels Annual SO_2 isopleths Annual particulate isopleths Wind
Precipitation	Amount of snow Amount of rainfall
Noise	Level
Solar radiation	Intensity
Surface Water	Temperature Dissolved O_2 Conductivity pH TDS (total dissolved solids) Total alkalinity Total hardness Cations (5) Anions (10) Nutrients (4)
Groundwater	Depth Sodium content Sulfate content Acidity

Table 5-1 (Continued)

COMPONENT	ATTRIBUTE
Soil	Physical characteristics Nutrients Radioactivity Moisture Temperature Depth Density Water content Frost depth
Sediment	Moisture T.K.N. (total Kjeldahl nitrogen) C.O.D. (chemical oxygen demand) Volatile solids Grain size analysis (Tyler screen) Heavy metals (spectrographic screen)
Coliforms Streptococci Pathogens	Amount
Periphyton	Accumulation Primary productivity Relative distribution
Benthos	Biomass Densities Relative distribution Species diversity (artificial substrate)
Fish	Average length Average weight Population estimates Length-frequency Growth Distribution of species
Songbirds Waterfowl Nocturnal Raptors Raptorial Prey Items	Density Average bird-use days Relative abundance Dominance Diversity indices

Table 5-1 (Continued)

COMPONENT	ATTRIBUTE
Arthropods	Relative abundance Species diversity Trophic level
Reptiles	Relative abundance Density Biomass Reproduction Food habits Age class
Small mammals	Density Biomass Reproduction Activity Food habits Age class Persistence
Coyote	Scent stations
Cottontail	Abundance
Deer	Pellet-group counts Browse utilization Mortality Age-class composition
Herbs	Biomass Current live standing crop Standing dead crop
Perennial Grasses & other major herbs	Phenophases

Table 5-1 (Continued)

COMPONENT	ATTRIBUTE
Mountain mahogany Serviceberry Big sagebrush Pinon-juniper (woodland) Big sage (bottom-land sage communities)	Litter and prostrate dead Decomposition (leaves) Stem length Shoot growth Lateral shoot development Cellulose control Litterfall Standing crop

Table 5-2. Example tally sheet listing components, attributes, and the processes they influence. Examples are from a terrestrial ecosystem on an oil shale development site in western Colorado. Numbers correspond to processes listed in Table 5-3 (modified from C-b Shale Oil Venture 1977).

	COMPONENT	ATTRIBUTE	PROCESSES
Natural Driving Variables	Air	Temperature	1,2,3,4,5,6,7,9,10,11,13,14, 15,20,21,22
	Atmosphere	Precipitation	12,14,19,20,22
	Atmosphere	Wind	10,12,14,19,20,22
	Atmosphere	Solar radiation	7
Man-Induced Driving Variables	Livestock	Numbers	1,3,8
	Sulfurous emissions	Concentration	7,11,13,16,17,21,23
	Nitrogenous emissions	Concentration	7,11,13,16,17,21,23
	Ozone and oxidant emissions	Concentration	7,11,13,16,17,21,23
	Trace metal contaminants	Concentration	2,4,5,6,7,11,13,16,17,21,23
	Carbon monoxide emissions	Concentration	2,4,5,6
	Water vapor emissions	Relative humidity	7
	Noise and activity	Level	1,2,3,4,5,8
	Hunting and recreation	Intensity	1,2,3,4,9
Abiotic State Variables	Surface water	Depth	1,3,4,14,20,21,22
	Top soil water	Tension	4,5,7,10,11,13,15,16,17,18, 23,24
	Bottom soil water	Tension	4,5,7,10,11,13,15,16,17,18, 23,24
	Top soil heat	Temperature	5,6,7,9,13,16,17,18,21,23,24
	Bottom soil heat	Temperature	5,6,7,9,13,16,17,18,23,24
Producer State Variables	Live shoots	Biomass	3,4,5,9,10,14,15,20,22
	Live roots	Biomass	4,5,9,10,14,15,18,24
	Standing dead	Biomass	4,5,9,14,20,22
	Aboveground litter	Biomass	4,5,9,20,22,24
	Belowground litter	Biomass	4,5,9,18

Table 5-2. (Continued)

	COMPONENT	ATTRIBUTE	PROCESSES
Consumer State Variables	Terrestrial animals	Numbers	1,2,3,4,5,6,8,12,14,18,19, 20,22,24
	Terrestrial animals	Weights	2,4,5,6,8,14,18,20,22,24

example of the kinds of components and their associated attributes that are commonly studied in the field to determine ecological baseline conditions on a development site.

To select attributes, consider three criteria:

1. The importance of an attribute in regulating flows of material or energy (currency) between ecosystem components.

2. The importance of an attribute from a legal or socioeconomic perspective.

3. State-of-the-art limitations on measuring each attribute.

Begin with the flow-control diagrams, which contain all the components and attributes already identified as conceptually important to the ecosystem. For each diagram, systematically list all components in a column, followed by their important attributes in a second column. For ease of organization, keep a separate list for each different category, such as natural driving variables, man-induced driving variables (perturbations), abiotic state variables, producer state variables, consumer state variables, etc.

Use these lists as tally sheets to keep track of the number of times a component and a particular attribute appear in the process diagrams. In a third column on the worksheets, list the process that is affected by each component and its attribute(s). From these sheets you can identify components and attributes that recur frequently, as well as the processes they influence. Categorizing components makes it easier to compare similar components and their attributes as they are grouped together. Such comparison often can help eliminate components or attributes that will provide only redundant or superfluous information if studied in the field.

An example of how this works is presented in Table 5-2. Components are listed with their attributes and the processes they affect. Note that numbers have been used to code and list processes. Each process has its own number (Table 5-3), which is then recorded on the tally sheet. Such a coding system is often easier to use than listing each process several times.

The tally sheet is used in many ways. For instance, a quick glance at it (Table 5-2) reveals that trace metal contaminants will probably disturb more ecological processes than any of the other oil shale development perturbations, whereas water vapor emissions will affect only one (photosynthesis). However, all of the first four oil shale perturbations will affect many processes, so they all probably should be measured carefully. Carbon monoxide emissions, though not affecting as many processes, will affect animal natality, mortality, growth, and respiration; it too, deserves attention.

Components on the tally sheet are highly aggregated. Thus, terrestrial animals constitute the component, with numbers being the attribute measured. However, it would be impossible to measure the numbers of all animals. Therefore, consider each affected process and how it might be influenced by animal numbers. For instance, the processes of shoot grazing output, shoot shattering, dead plant grazing output, dead plant shattering, and aboveground litter grazing output will all be affected by aboveground herbivore numbers, whereas belowground

Table 5-3. List of 24 processes that control flows in three flow currency subsystems on an oil shale tract (C-b Shale Oil Venture 1977).

SUBSYSTEM	NUMBER	PROCESS
Animal Population Numbers	1	Immigration
	2	Natality
	3	Emigration
	4	Mortality
Animal Weights	5	Growth
	6	Respiration
Plant Carbon Biomass	7	Photosynthesis
	8	Excretion input
	9	Dead animal input
	10	Translocation to roots
	11	Shoot death
	13	Shoot respiration
	14	Shoot grazing output
	15	Translocation to shoots
	16	Root death
	17	Root respiration
	18	Root grazing output
	19	Dead plant shattering
	20	Dead plant grazing output
	21	Aboveground decomposition
	22	Aboveground litter grazing output
	23	Belowground decomposition
	24	Belowground litter grazing output

litter grazing output will be influenced by soil arthropods and other underground herbivorous organisms. The species of aboveground herbivores is important as well: cattle graze differently from sheep. In some cases, it will be necessary to identify the key species that need to be measured, depending, in part, on the type of vegetation on the site.

5.2.1 Use the Model to Identify Important Components

The model consists of the major materials developed by procedures discussed in Chapter 4: the impact matrix (Figure 4-17), the documentation of those impacts (Table 4-10), the process diagrams (Figure 4-18), and the system control diagram(s) (Figure 4-20). Use these materials with the tally sheets to further identify important components. The documentation of impacts, for instance, should provide a key to how seriously a perturbation will affect a specific process. Lists of species generated by steps in Chapter 3 will help determine what species can be used to represent the more aggregated components. Finally, trace any anticipated serious effects through the system control diagram to determine how far-reaching those effects might be.

Developing the model was a systematic process, but it still required much ecological judgment during construction. Similarly, selecting attributes to measure in a baseline study is partly judgmental, and as such, is somewhat of an art aided by science. The documentation and numbers generated by the steps in the study up to this point help assure that nothing important is overlooked, but the final decision about what to measure is largely judgment, based on the materials developed. Whatever attributes are selected, they will be a tradeoff between too much superfluous data and not enough of the right data.

5.2.2 Socioeconomic and Legal Considerations

After selecting the list of attributes to measure based on considerations of ecological and energy-development criteria, check the list against the constraints and requirements that were identified by Chapter 2 procedures. For instance, if certain types of habitat are likely to provide nesting sites for a rare or endangered species of bird, even if there has never been a sighting, those habitats should be studied very carefully to determine whether that species is found there. Also include in the study scenic considerations that might have no intrinsic value to the ecosystem, but which are otherwise important, e.g., from a recreational standpoint.

Of course, the legal requirements will be spelled out more or less clearly, and these, too, must be addressed. As was mentioned in Chapter 2, if the requirements are not clear, get official clarification about what must be measured or studied. Review your lists of components and attributes with persons in the decisionmaking framework as part of the open planning concept. Be prepared to document or discuss why a particular component or attribute was chosen, or why it was left out.

5.2.3 State-of-the-Art Constraints

After generating a preliminary list of components and attributes to measure, consider the practicability of measuring each of them. This is better done while planning the methods to be used in the field study. The state-of-the-art and other practical limitations of measurements will become apparent when you try to select the parameters of an attribute and the field techniques necessary to measure those parameters.

Biomass, for example, can be measured and described in several ways: live weight, air-dry weight, oven-dry weight, etc. How to choose specific parameters, their units, and methods for measuring them are the subject of Chapter 6. When limitations arise, choose another attribute in such a way as to minimize loss of information about that component.

6.0 SELECT APPLICABLE EXPERIMENTAL METHODS

6.1 INTRODUCTION AND OVERVIEW

Earlier chapters identified ecosystem components, processes, perturbations, and attributes that are important for legal, socioeconomic, or ecological reasons. These chapters are designed to lead systematically to choosing effective methods for measuring ecosystem parameters. This chapter reviews current methods and comments on them for both terrestrial and aquatic ecosystems in the areas of the United States where energy development is expected. These methods are suitable for a wide range of ecological baseline studies; our task is to select the methods that most effectively measure parameters of attributes identified earlier.

The concepts of resolution and time horizon must be kept in mind when selecting a method. Most ecological data are time-related: They assume different values according to diurnal, seasonal, or annual fluctuations. For these reasons, field studies should coincide as much as possible with times that are ecologically important.

Consider, therefore, what can reasonably be accomplished during the study period. A common objective of baseline studies has been to provide a "benchmark" against which future changes in the system can be evaluated. Natural fluctuations, however, seldom allow site-specific data to be gathered concerning attribute variability within the time constraints of a baseline study. In many situations, studying indicator components and components of low variability might be more productive than studying highly variable components. Sometimes literature reviews and pilot studies may be required to determine the natural variability of a component and the status of that component within the study area. If highly variable components are of concern, monitoring control and impacted areas may provide more reliable results than before-after data comparisons.

In the following discussion more than one method of study is cited for most parameters; this provides a cross-section of available techniques and maximizes the likelihood that a good reference will be readily accessible to the study designers. Because the field of ecology is extremely broad and the state of the art has advanced rapidly in recent years, the list of methods is not all-inclusive.

This chapter suggests techniques for designing a program, selecting parameters or alternate attributes, and identifying useful study methods. It is not intended that this manual should serve as a substitute for experienced biologists; rather, it should assist in making professional judgments about the components to be studied, levels of detail, time frames, and specific methods.

The following design procedures should be followed for all important ecological components or processes to be studied:

1. Review objectives of the study.
2. Review pertinent site-specific and regional ecological literature.
3. Conduct a pilot study or a reconnaissance of the area, if necessary.
4. Determine cost, manpower, and time constraints.
5. Decide whether there will be: no study, a qualitative study, or a quantitative study.
6. Select techniques and site-specific procedures.
7. Choose a sample size large enough for study objectives (e.g., species composition, point-in-time population estimate, seasonal population changes, sex ratio, age ratio).
8. Make sure the sampling schedule is adequate for study objectives (e.g., daily population changes, seasonal population changes, within-season population changes).
9. Choose study areas suitable for between-habitat comparisons (e.g., homogeneity requirements, structural requirements).
10. Calibrate parameter estimates for indirect population measures (e.g., nests, pellets, tracks) to the population being measured (e.g., nests per squirrel, pellet groups per deer per day).

6.2 STATISTICAL CONSIDERATIONS

The subject of statistics often carries with it a certain mystique. However, statistics has become an integral part of ecological research. In fact, statistics is so much a part of ecological studies that it is virtually impossible to divorce field and laboratory techniques from applied statistics. For this reason, statistical techniques are discussed with the various field and laboratory methods outlined below.

Because of the breadth of materials on statistical analysis available in many excellent texts, it is beyond the scope of this manual to set forth detailed explanations of how to design experiments and plan sampling from a statistical perspective. Rather, it is the purpose of this section to emphasize the need for sound statistical considerations in ecological baseline studies and to discuss some broad aspects of applied statistics.

6.2.1 Why use statistics?

The main reason for using statistics is that ecological phenomena vary; there is no such thing as a "typical" fish, tree, or insect. Statistics allows us to draw inferences from the specific ecological measurements we make and to generalize about those measurements with some degree of confidence.

Variability is not restricted to what we measure, however. Although variability is inherent in measured phenomena, other sources of ecological variability include observer error, equipment malfunction, differences in sampling techniques, and seasonality. Often confusion arises between natural variability and seasonal variability. Where this confusion exists, statistics cannot replace experience and sound judgment in determining when to sample. This is one of the limitations of statistics. The ecologist must understand enough about statistics to realize its limitations, or he must work with someone who does.

6.2.2 Objectives of Statistics

Freese (1967) lists two basic objectives of parametric statistical methods:

1. The estimation of population parameters.

2. The testing of hypotheses about those parameters.

The purpose of developing a field portion of an ecological baseline study is to gather data about the study site that are not available elsewhere. Generally we wish to measure the important ecological parameters as identified by the conceptual model. To do this we sample from the existing population on the site, using one or more replicates, if necessary, to estimate the true value of each population parameter.

This true value (statistical parameter) will be approximated by some number when the data are reduced. This numerical point estimate will fall along a spectrum of values that encompasses the normal range of variability for that parameter. Often this estimate is the arithmetic mean of the sample.

How well the point estimate of the population parameter approximates the true value of that parameter depends on the sample size, number of replicates, and natural variability. We can, however, make a quantitative inference about that point estimate by employing an interval estimate. An interval estimate is simply an estimate of the range in values that point estimates of the parameter are likely to take. A commonly used measure of dispersion is the standard error about the mean of the population being sampled.

Using the standard error and certain probability tables, we can calculate upper and lower limits about the point estimate. Furthermore, we can state quantitatively how likely it is that the true value of the parameter lies within those limits. These confidence limits are customarily chosen at 95% or 99%, although there is nothing sacred about either number. Thus, we can state that the true value of the population parameter lies within these limits 95 times out of 100 (95% confidence limits) or 99 times out of 100 (99% confidence limits).

When selecting confidence limits, however, the biological investigator must think in terms of both statistical significance and ecological significance. Many times a high level of effort is required to obtain 95 to 99% confidence. Other confidence levels (e.g., 80%, 90%) may be adequate to describe the biological component and to make a decision concerning that component. Because of time and cost constraints, the designer must often study various components at a level commensurate with their ecological importance. If only the 95% confidence level were acceptable, many biological studies would be eliminated from the sampling programs.

Many of the same principles apply to testing hypotheses about the parameters we estimate. Often we wish to compare populations by drawing inferences from the samples we have taken from the populations. A common hypothesis is that no difference exists between two or more populations on which a common parameter was measured. Statistical methods allow us to state, again with some quantitative level of confidence, whether the populations are truly different, or whether variability among point estimates from each population is simply due to inherent variability. The usefulness of this particular technique becomes apparent in baseline studies in which we wish to compare ecological response units, or in which we wish to use the results of the baseline study to compare monitoring results after development has begun.

The important things to remember about statistics are (1) that we are almost always trying to draw an inference from the particular (a sample) to the general (a population), and (2) that uncertainty is always present. Statistical inference provides a quantitative estimate of that uncertainty and of the degree of confidence that may be placed in any hypothesis; it provides an estimate of the chance that a given value is erroneous in one way or another.

Many biological field studies, however, cannot meet all the assumptions necessary for using parametric statistics. In these situations the designer should consider nonparametric statistics, which can be nearly as "powerful" as parametric statistics. Biological studies often must find the best habitats and the worst habitats; the information is then to be used in locating various facilities (e.g., buildings, reservoirs, discharge structures). Nonparametrics can be used to test for differences between the habitats in question. Statistics, then, is simply a kit of tools for organizing facts and observations and for reasoning about the meanings of those observations so they are more easily and confidently studied.

6.2.3 Randomness, Bias, Precision, and Accuracy

The inherent variability in ecological phenomena requires that we sample in such a way that our estimate approximates the true value of each population parameter. The only way we can be sure of doing this, over the long-term average, is to plan the sampling so that every individual sampled has an equal chance of being chosen. This is the definition of randomness, and any sample thus chosen is known as a random sample. Methods for obtaining random samples are beyond the scope of this manual, but they are essential to sound statistical analysis.

If, for example, we are sampling vegetation and we locate the quadrat only in those places that are convenient to sample in, we will not be taking a random sample. In fact, we will be biasing the results. Bias simply means systematic distortion (Freese 1962). Thus, in this example, we are biasing the sample in favor of those plants that are convenient to measure. Another example of bias is an instrument that is not calibrated correctly, so that each measurement is off, either by a fixed amount or by a relative amount (e.g., drag on a meter needle that increases in proportion to the distance traveled by the needle).

Accuracy refers to how closely the true value of a parameter is estimated. Thus, a biased estimate is not accurate, although it may be precise. Precision, as used in statistics, refers to how closely sample values cluster about their own mean. If a sample is biased, the mean will not be an accurate estimate of the parameter, although the sample may be very precise, in that the repeated measurements may be very close to each other.

6.2.4 Scope of Statistics

Ostle and Mensing (1975) summarize the scope of statistics as:

- Designing experiments and surveys.
- Collecting, reducing, and summarizing data.
- Estimating population parameters and providing measures of accuracy and precision of those estimates.
- Measuring the magnitude of variation in both experimental and survey data.
- Testing hypotheses about populations.
- Studying relationships among two or more variables.

Details of how this scope can be applied to ecological baseline studies are discussed in the sections dealing with specific techniques of ecological measurement.

6.2.5 Sampling and Experimental Design

Developing a program to sample ecological parameters requires some knowledge of those parameters beforehand. The reason for this is that the variability of a given parameter will dictate the sample size needed to be taken in order to place reliable confidence limits on the point estimate of that parameter. Sometimes, this information may be gleaned from the scientific literature, but often a pilot study is required to get some measure of variability.

Location of sampling plots and the number of replicates needed are part of experimental design procedures. Sampling locations must be chosen to represent all major habitat types or ecological response units, depending on what is needed. Many experimental design techniques were developed in agricultural studies that tried to detect differences between various treatments of plants and animals. Such agricultural studies are quite similar to many ecological baseline studies. Different treatments result from different climatic regimes or conditions before and after development begins. Experimental design techniques are extremely useful for planning baseline studies to maximize information and valid inferences while minimizing costs.

Control sites provide a basis for before-and-after comparisons if they are chosen outside the area of expected impact from the development. They should be paired with experimental sites within the area of expected impact. Replications will be dictated by the inherent variability of the parameters being measured and by the potential danger of losing plots due to changes in development plans. Control sites are also used in spatial comparisons at a moment in time.

6.2.6 Commonly Used Statistics and Methods

There are basically two types of variables to which statistics are applied: measured variables and derived variables. As the name implies, measured variables are direct observations or measurements of an ecological parameter. Derived variables are computed from measured variables. They include such things as rates, ratios, percentages, and indices. Some of the problems encountered with derived variables are discussed by Sokal and Rohlf (1969).

The statistics commonly used to estimate these variables are the arithmetic mean, the variance, and the standard error about the mean. These three statistics can be used in a variety of statistical applications to determine confidence intervals or to test hypotheses about the population. The analysis of variance for example, is an extremely powerful tool for comparing statistics among several populations or treatments.

Correlation analysis is used to determinine whether two or more population parameters are related in any way; regression analysis allows us to predict the quantitative behavior of one variable from a knowledge of one or more of the other variables.

These techniques and the tests that can be used with them can be found in statistics texts. Many are discussed below in conjunction with ecological field measurement techniques.

6.2.7 What to Do Till The Statistician Comes

One of the major advantages of planning a statistically sound ecological baseline study is that it will probably cost less, in the long run, to do it right. A common result of poor planning is a deluge of data that are expensive but virtually unusable. The earlier sections introduced some basic concepts and problems of gathering biological data. This section suggests specific checklists to use in planning the study before you consult the statistician.

Cochran and Cox (1957) suggest beginning with a written draft of the proposals for any experiment. This draft should include (1) a statement of the objectives; (2) a description of the experiment and the experimental material; and (3) a discussion of methods for analyzing results. Developing the conceptual model will already have provided background to do this.

Within this broad framework, the following expanded list describing "a statistically designed experiment" provides more detail (modified from Ostle and Mensing 1975):

1. State the problem.

2. Formulate objectives for the study, both primary and secondary objectives, if possible, within existing limitations.

3. Devise experimental technique and design; define exact scope of the study program.

4. Examine possible outcomes (e.g., impacts) and refer back to the reasons for the inquiry to be sure the study provides the required information; i.e., determine relationship of the particular problem to the whole proposed development program (e.g., a long-term monitoring and mitigation program).

5. Conduct a pilot study or a reconnaissance of the area, if possible.

6. Consider the possible results from the point of view of statistical procedures that will be applied to them, to ensure that the conditions necessary for these procedures to be valid (i.e., the underlying assumptions) are satisfied.

7. Perform the study.

8. Apply statistical techniques to the experimental results.

9. Draw conclusions from measures of the reliability of estimates of quantities that are evaluated; give careful consideration to the validity of the conclusions for the population of objects or events to which they apply.

10. Evaluate the whole investigation, particularly with other investigations on the same or similar problems.

Finally, before actually going into conference with a statistician, consider the following expanded guidelines in terms of an ecological baseline study. It, too, is modified from Ostle and Mensing (1975). Begin by obtaining a clear statement of the problem as suggested in Steps 1 through 4 above.

Collect available background information.

1. Investigate all available sources of information.

2. Tabulate data pertinent to planning new ecological studies.

(These two steps have already been done in building the conceptual model.)

Design the study.

1. Hold a conference of all parties concerned.

   - List the components, attributes, and parameters to be measured and the hypotheses to be tested.
   - Agree on the magnitude of differences considered worthwhile (i.e., ecological significance).
   - Outline the possible alternative outcomes.
   - Determine the practical range of the parameters and the specific confidence levels at which tests will be made.
   - Choose the end measurements that are to be made (i.e., parameters and their units).
   - Consider the effect of sampling variability and of precision of sampling methods.
   - Consider natural variability.
   - Consider possible interrelationships (or "interactions") of the components and/or ecological response units (ERU's).
   - Determine limitations of time, cost, materials, manpower, instrumentation and other facilities.
   - Determine limitations of weather, topography, and other physical constraints.
   - Consider human relation aspects of the program.

2. Design the study in preliminary form.

   - Prepare a systematic and inclusive sampling schedule (e.g., include daily population changes, seasonal population changes, and within-season population changes).
   - Provide for step-wise performance or adaptation of schedule if necessary.
   - Select suitable study areas for proposed between-habitat comparisons (e.g., homogeneity requirements, structural requirements).
   - Eliminate the effect of variables not under study by controlling, balancing, or randomizing them (this is often difficult in studies of natural systems, but these variables should at least be documented).
   - Choose the method of statistical analysis.

- Arrange for orderly accumulation of data.
- Minimize variations in methodology between ERU's or other study area units.

3. Review the design with all concerned.
    - Adjust the program in line with comments.
    - Spell out in unmistakable terms the steps to be followed.

Plan and carry out the experimental work.

1. Develop methods, materials, and equipment.
2. Apply the methods or techniques.
3. Attend to and check details.
4. Minimize changes in the program; modify methods only as necessary.
5. Record any modifications of program design.
6. Take precautions in collection of data.
7. Record progress of the program.

Analyze the data.

1. Reduce recorded data to numerical form, if necessary. Calibrate parameter estimates for indirect measures of component (e.g., nests per squirrel, pellet groups per deer per day).
2. Apply proper statistical techniques.
3. Apply proper graphic analytical techniques.
4. Arrive at conclusions about ecological significance of results as well as their statistical significance.
5. Point out implications of the findings for application for further work.
6. Account for any limitations imposed by the methods used.
7. State results in terms of verifiable probabilities.

Prepare the baseline study report.

1. Describe work clearly, giving background, pertinence of the problems to the proposed project, and meaning of results.
2. Use tabular and graphic methods of presenting data.

3. Supply sufficient information to permit reader to verify results and draw his own conclusions.

4. Limit conclusions to objective summary of evidence so that the work recommends itself for prompt consideration and decisive action.

6.3 HABITAT

Because habitat includes all the components, both biotic and abiotic, necessary for the survival of a species (e.g., food, cover, water, breeding and parturition areas), knowing the general habitat requirements and biology of a species allows you to determine the potential value of an area for wildlife. Ideally, evaluations of habitat should include all the requirements of all species present, but the time-frame of most baseline studies does not permit this level of detail. (It is also unlikely that all habitat requirements of any wildlife species will ever be fully understood.) Therefore, such evaluations often involve measuring only a few parameters of the environment believed to be important to the survival of selected species.

6.3.1 A New Assessment Technique

Habitat evaluations (quantitative or qualitative) hold great promise for improving terrestrial baseline studies because they can apply a particular value to an area. They can also be used to help select ecological response units for developing a conceptual model of the area. However, because evaluating habitat is extremely complex, it requires a uniform, systematic approach that is applicable to a wide variety of habitat types.

One such approach that allows the user to apply a value systematically to a habitat was recently developed by the U.S. Fish and Wildlife Service (1976) in cooperation with various conservation groups and state and other federal agencies. Called Habitat Evaluation Procedures (HEP), the technique is designed to provide a consistent means of assessing project development impacts by: 1) assigning a quantitative index value for existing habitat conditions; 2) determining the difference between index values of existing conditions and conditions that will result from a proposed project; and 3) demonstrating, in habitat-value units gained or lost, the beneficial or adverse impacts anticipated as a result of projected development. Further information about this technique is available from the National Coordinator, Project Impact Evaluation, U.S. Fish and Wildlife Service, Suite #11, 333 West Drake Road, Fort Collins, Colorado 80521.

6.3.2 Other Methods

In addition to the new method discussed in the previous section, many other standard methods are available, most of them closely tied to mapping vegetation. Specific vegetation-analysis techniques for habitat evaluation are discussed in the next section along with general methods for studying vegetation. However, some broad guidelines that apply to either the general process of selecting ecological response units or the more detailed process of evaluating habitat for a particular species follow:

Use the information base collected for the conceptual model to identify data on biotic resources that will likely be impacted by the proposed project. From this, identify representative wildlife species that occur in each vegetation type. In the past, habitat evaluations have been centered primarily around threatened, endangered, or game species because of their legal or economic status. However, habitat evaluations should include representative species from all vertebrate groups. Species should represent various niches in the vegetation community and should have a high degree of affinity for a vegetative type. In practice, however, the number of species chosen may often be limited by lack of information about their habitat requirements.

Next, appraise characteristics of a particular vegetation type on the basis of their value in providing habitat requirements for the species selected. These assessments often focus on attributes that are believed to be limiting factors to the survival or presence of a species. Evaluate appropriate vegetation, soils, fauna, and additional biotic factors to arrive at a habitat value for individual or groups of wildlife species. Many of these evaluations and measurements will be identical to the specific floral, faunal, and abiotic measurements discussed later in this chapter, which will, of course, be based primarily on the conceptual model. However, if the degree of aggregation in the model is too great to include certain critical habitat evaluations, these habitats should be evaluated in addition to the parameters and measurements suggested by the model.

For example, an estimate of overstory cover might have little meaning in terms of habitat value unless the cover is related to the needs of a particular species or group of species of wildlife. Habitat evaluation methods depend on attributes of the habitat. Attributes of vegetation that are useful for evaluating habitat are species composition, productivity, condition of browse species, and forage availability, for instance. Types and textures of soils also provide information on wildlife habitat (e.g., nutrient contents of wildlife food plants vary considerably with soil conditions; soil texture may determine the suitability of a site for burrowing animals). The relative abundance, diversity, distribution, or reproductive success of other animal species are often important to a particular wildlife species in terms of territory, predator-prey relationships, etc. Certain abiotic features are also important to the presence or survival of a wildlife. For example, cliff-nesting sites may determine the potential presence or absence of certain raptors, or the lack of available surface water every few miles may curtail the use of otherwise suitable habitat by big game species.

The conceptual model identifies important species or groups of species in the baseline study area and the ecological response units in which they live; habitat evaluation provides a means of determining how some of the proposed modifications to their environment will affect those species. Habitat evaluation for baseline studies, when used with the conceptual model of the area, may provide particularly useful basis for estimating future impact to wildlife and for recommending mitigative measures, siting alternatives, or project alterations to minimize impacts.

6.4 TERRESTRIAL SYSTEMS

Terrestrial systems comprise the following autotrophic and heterotrophic components: Autotrophs include some soil microbiota, most nonvascular plants, and vascular plants. Heterotrophs include most soil microbiota, invertebrates, and vertebrates.

6.4.1 Vegetation

Vegetation usually provides the most important information in baseline studies for two reasons: It is an integrator of many important abiotic factors, such as climate and soils, and it provides food and shelter for wildlife.

Vegetation studies provide valuable information about the following site characteristics: successional status, community complexity, ecological stability, productivity, habitat potential for wildlife, past and present land-use practices, past and present environmental perturbations, and recreational potential. As integrators, plants often reflect past and present climatological, atmospheric, hydrologic, or edaphic conditions, as well as natural or man-induced changes in these conditions. Vegetation also provides indirect evidence of the presence of wildlife. Plant communities are nonmobile, and they usually change relatively slowly in an orderly fashion (e.g., succession), unless disturbed by natural or man-made perturbations.

Problems associated with studying plant communities are that sampling methods are time-consuming. High levels of expertise are often required for designing and executing field studies and interpreting data. Often vegetation data frequently provide an indirect measure of other important ecosystem characteristics. For instance, vegetation indicates potential for wildlife habitat, soil erosion, or recreation, but it does not provide accurate numbers of wildlife species, tons of erosion, or visitor-days in an area.

Field studies should include information on all strata, if more than one stratum exists. Strata are commonly defined as follows:

- Ground stratum - stems less than 1 m in height.
- Shrub stratum - stems greater than 1 m in height but less than 2.5 cm diameter at breast height (DBH), where breast height is considered to be 1.5 m.
- Tree stratum - stems greater than 2.5 cm DBH.

6.4.1.1 Standard Techniques: An Overview. To measure specific parameters associated with vegetation attributes you will need to choose from a wide variety of techniques. Fortunately, a relatively few references cover most of the standard methods. Methods and references are presented in Table 6-1 along with common attributes and parameters.

However, if you wish to use techniques that are more specialized, innovative, or sophisticated, Table 6-2 contains supplementary references, many of which are annotated in Appendix C. These annotations provide additional insights into the usefulness of the references for applying particular techniques in a given situation. When using Tables 6-1 and 6-2 and the annotated

Table 6-1. Standard ecological attributes, parameters, methods, and references for evaluating vegetative components of the ecosystem. Numbers refer to references cited in Table 6-2.

ATTRIBUTE	PARAMETER	HERBACEOUS		WOODY	
		Method	Reference	Method	Reference
Species Composition	Name	Plot	24,51	Plots, Plotless, Line Intercept	19,24,51
Diversity	Various indices	Data analysis	55	Data analysis	55
Height	Meters or feet	Plot	30	Mechanical (prisms, clinometers)	70
Cover	Percent	Plot	24	Plot, Line Intercept	15,24
Density	Number/Unit Area	Plot	24	Plotless, plot	19,24
Utilization by Consumers	Kilograms/Hectare Pounds/Acre Percent Qualitative Rating	Plot, Plotless ocular, transect, plot	64	Plotless, Plot	1
Frequency of Occurrence	Percent	Plot, Plotless	24,51,53	Plotless, Plot, Line Intercept	24
Distribution	Areal extant Qualitative map	Mapping from remote sensing sources	38	Mapping from remote sensing sources	38
Standing Crop/Biomass (productivity for woody species)	Kilograms/Hectare Pounds/Acre	Clipping, Ocular estimate	17,44	Twig count weight estimate	61
Age	Years	--	--	cores	70
Basal Area	Stem Area/Unit Area	Plot, Line Intercept	24,15	Plot, Plotless	19,24,54
Timber Volume	Board-Feet Cubic Feet Cords	--	--	Plotless	11,31

Table 6-2. References for methods commonly used in collecting and analyzing data on vascuar plants for terrestrial baseline studies. Use the annotated bibliography (Appendix C) for specific information about each reference.

	Method	
	Field and Laboratory	Data Analysis
Herbaceous Vascular Plants	General Sampling(a) 2,7,14,22,24,28,47,51,52,54,56	Same
	Mapping and Aerial Remote Sensing 3,12,13,20,36,38,62	Same and also 10,48, and 68
	Habitat Evaluations 9,10,12,13,21,38,65	Same
	Range Sampling 9,10,17,23,43,44	Same
	Production Estimates 7,9,10,14,17,22,43,44,47,50,56,63,65	Same
	Cover Estimates 7,9,10,12,14,17,18,22,26,33,39,43,44,45,47,52,54,63,67,68	Same
	Density Studies 5,7,39,40,56,67	Same
	Frequency of Occurrence 34,35,57,60,67	Same
Woody Plants	General Sampling 7,14,19,22,24,28,31,47,51,54,56,66,70	Same
	Mapping and Aerial Remote Sensing - see "Herbaceous Vascular Plants"	Same
	Range Sampling 8,9,10,11,17,23,49	Same
	Production Estimates 4,6,9,10,29,32,39,42,46,56,58,59,61	Same
	Commercial Forestland Evaluation 11,31,70	Same

Table 6-2 (Continued)

	Method	
	Field and Laboratory	Data Analysis
Woody Plants (Continued)	Cover Estimates 7,16,18,25,26,37,39,47,56	Same
	Density Estimates 27,39,41,47,56	Same
	Frequency of Occurrence 34,47,60	Same

(a) References

1. Aldous 1944
2. Atkinson 1975
3. Avery 1968
4. Basile and Hutchings 1966
5. Becker and Crocket 1973
6. Bentley et al. 1970
7. Bower and Zar 1977
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10. Bureau of Land Management Manual Section 4412
11. Bureau of Land Management Manual Section 5000
12. Bureau of Land Management Manual Section 6602
13. Bureau of Land Management Manual Section 6610
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17. Cook and Bonham 1977
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19. Cottam and Curtis 1956
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22. Cox 1976
23. Cunningham 1975
24. Daubenmire 1968
25. Fisser 1961
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27. Franklin 1967
28. Greig-Smith 1964
29. Halls and Harlow 1971
30. Heady 1957
31. Husch et al. 1972
32. Hutchings and Mason 1970
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34. Hyder et al. 1963
35. Hyder et al. 1965
36. Johnson 1969
37. Kinsinger et al. 1960
38. Kuchler 1967
39. Laycock 1965
40. Laycock and Batchler 1975
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43. Mamnette and Haydock 1963
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45. Morris 1973
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47. Mueller-Oombois and Ellenberg 1974
48. National Academy of Sciences 1970
49. Neal 1973
50. Neal et al. 1976
51. Oosting 1956
52. Owensby 1973
53. Parker and Harris 1959
54. Phillips 1959
55. Pielou 1975
56. Pieper 1973
57. Poissonet et al. 1973

Table 6-2 (Continued)

(a) References Continued

58. Rittenhouse and Sneva 1977
59. Schuster 1965
60. Scott 1965
61. Shafer 1963
62. Shimwell 1971
63. Singh et al. 1975
64. Smith, Currie, Basile, and Frischknecht 1963
65. Soil Conservation Service 1976
66. Spurr and Barnes 1973
67. Walker 1970
68. Way 1973
69. Winkwath et al. 1962
70. Forbes 1961

bibliography for preliminary planning of a field-sampling program, keep in mind the statistical considerations discussed in Section 6.2. Decide how the data you collect will be analyzed, how they will be used, and how they will be presented to decisionmakers. Most of the references cited suggest specific statistical procedures that work best with a particular field-sampling technique. Use these references to help plan the sampling regime, plot locations, etc., that will provide data most suitable for your specific study. Finally, the field method you choose will depend heavily on the type of vegetation being studied. Techniques that work well for measuring herbaceous vegetation in grasslands might not be suited to brushlands or forests. This is the main reason that this manual cannot be more specific in recommending field methods: Site conditions strongly influence the choice of specific sampling design and field measurement techniques.

Nonetheless, you should be aware of some general considerations in selecting methods and options, as well as some of the potential problems in sampling. For instance, you will have to decide where transects or plots will be located. A transect is simply a line through vegetation to help locate spots where samples will be taken. Plots are areas within which sampling is done, although many plotless sampling techniques also exist. A transect can be used either to locate plots or to make point estimates of vegetation. How and where transects or plots are located can seriously affect results of a study. Exceptionally dense or sparse vegetation can influence decisions about where plots or transects are placed. Data from such biased placement will probably overestimate or underestimate certain attributes, such as biomass, density, and cover, for example.

Another important consideration is the size and shape of the plots. Certain sizes and shapes have been found more accurate than others in a particular type of vegetation. The same is true of different harvesting techniques: Some are more efficient and accurate than others, often depending on the vegetation. If you do not wish to use destructive sampling, a wide variety of nondestructive methods are available. They range from simple, ocular estimates through measurements of certain plant parts, to sophisticated gaseous-exchange, chlorophyll-analysis, radioactive-tracer, and electronic techniques. These latter are very specialized and usually require expensive equipment and highly trained personnel.

In addition to these direct methods, many indirect estimates are often used. In these, estimates or measurements of one or more attributes are used to estimate other attributes, usually through some mathematical formula, such as a ratio, or a statistical procedure, such as regression analysis. The accuracy of ocular estimates, for example, can be checked, calibrated, and correlated with harvest measurements by clipping after the ocular estimate is made. If the correlation between the two is good, ocular estimates for plots over the rest of the area can be made faster and cheaper than clipping and analyzing the vegetation in those same plots. Examples of other indirect methods include estimating biomass from measurements of vegetation height, leaf area, cover, etc.

One of the commonest ways to study vegetation is to map it. Very likely the initial information base will contain aerial photos or vegetation maps of the area where the study will be conducted. If not, you will probably need such tools to help plan the location and arrangement of transects and/or plots. Photographs and maps should delineate relatively homogeneous communities, some of which might also serve as ecological response units, or homogeneous portions of communities dominated by certain plant species. These graphic aids can be used for both herbaceous and woody vegetation.

In general, when selecting boundaries and locating plots and transects, remember that the accuracy and precision of estimates will be heavily influenced by the homogeneity of any site: The more accurate the estimate must be, the more homogeneous the study area must be. Estimates are also influenced by the size or number of samples taken.

6.4.1.2 Herbaceous Vascular Plants. Herbaceous vascular plants are non-woody, rooted annual and perennial grasses and forbs. As the primary ground stratum, herbaceous vegetation dominates early successional stages in every community, and all seral stages in prairie communities. These plants are important in cycling nutrients, contributing organic matter to soils, modifying microclimate, stabilizing soils, decreasing runoff, and increasing groundwater, while providing food and cover to wildlife, forage to livestock, and beauty to man.

The conceptual model of the ecosystem will assist in determining which attributes of herbaceous vegetation to measure. In some cases ocular estimates will be sufficient, while other studies may require rigorous statistical design using transects and plots. At the minimum, ocular estimates of ground strata should include cover, dominant vascular plants, and, if important, fungi, mosses, and lichens.

For quantitative data, various intercept techniques along a transect can be used while sampling other strata. For example, while sampling shrub or tree strata in a plot, you can use one side of the plot as a transect for sampling herbaceous vegetation. A line-intercept method, which makes observations along the line at random, is most useful in sparse vegetation; a point-intercept method, which records species occurring at regular, predetermined intervals along the transect, is better for dense vegetation.

A set of nested plots is sometimes useful for measuring different strata simultaneously. For example, small ground-stratum plots can be used within larger shrub-stratum plots, which are nested within still larger tree-stratum plots. Generally, rectangular plots are more accurate than circular plots.

In some cases, permanent plots might be necessary. For instance, if the baseline study is being conducted as part of a basis for planning longterm monitoring, permanent plots will probably be required. Consult maps of the topography and vegetation, as well as the conceptual model, to determine how many plots are needed and where they will be placed.

Where livestock are important, other methods that differ somewhat from classical plant-ecology techniques have been developed to evaluate the productivity of rangelands for grazing and browsing by domestic and wild ungulates. Bureau of Land Management and Soil Conservation Service manuals are particularly useful for developing site indices, estimating forage utilization, and determining forage availability and range condition.

In general, sampling techniques for herbaceous vegetation are not as efficient in obtaining quantitative data as techniques for sampling woody plants. As a result, much of the data obtained is only semi-quantitative. However, herbaceous plants are among the few biotic components for which productivity can be estimated quite reliably. A large number of sampling techniques are available, but often the time required to obtain accurate estimates of parameters is excessive.

6.4.1.3 Woody Plants. Woody plants are shrubs and trees. Just as herbaceous plants, they help stabilize soils, contribute organic matter to soils, cycle nutrients, decrease surface runoff, increase groundwater recharge, provide food and cover to wildlife, and modify microclimate. They also provide forest products, browse, and beauty.

Where woody plants dominate woodlands and shrublands, it might not be necessary to study herbaceous vegetation as intensely as in a grassland or meadow. However, the conceptual model will provide guidance for this. Many sampling methods for woody plants are similar to those for herbaceous plants, but others are quite different. Qualitative and semiquantitative ocular estimates of species composition, cover, and density may be adequate for certain studies. In others, more quantitative methods may be required.

Select a method on the basis of vegetation type, vegetative structure, areal extent of the community, and terrain. If an area is large and reasonably homogeneous, a plot or plotless type of sampling is generally better than transects. If an area is too small to be free of external influence and edge effect, or is highly heterogeneous (e.g., a stream valley with opposing slopes), a transect is better.

Where woody vegetation dominates, select a sampling method that favors data on woody plants, but not to the exclusion of herbs. Sampling should include all three strata. Often tree data may be segregated to provide information on pole timber and saw timber. Data collected for ground and shrub strata are generally in relative units, such as percent cover, or some rating or ranking system. Also consider estimates of fungi, moss, or lichen cover, and species composition. Shrub and ground strata are particularly important for evaluating the food and cover potential for wildlife.

Data collected about trees commonly include canopy cover, basal area, and timber volume. Age of the dominants in the canopy stratum provides an indication of past growth rates. Size class generally is useful in gauging successional trends. Height of each stratum in conjunction with the measurement of cover can be used to evaluate biomass. Biomass of the above-ground portion of plants is commonly determined for the ground and shrub strata. Although some attributes of woody plants can be sampled at any time of year, cover values are directly related to season and are generally most accurate if estimated in middle to late summer.

6.4.2 Animals

The animal ecosystem components and processes are extremely complex. Animals depend not only on the abiotic components, but also on the autotrophic components of the ecosystem. Animals may be influenced by abiotic processes directly, through changes in weather, or indirectly, through vegetation changes brought about by abiotic and biotic factors. In addition, variation in animal mobility, habitat requirements, home ranges, behavior, and biological rhythms (e.g., reproductive cycle, feeding periodicity, life cycle) all add to the difficulty of making meaningful measurements on animals. Despite these problems, animals are integral to ecosystems and should be studied as such.

Principal criteria for selecting species to study are:

1. Species that are valuable recreationally (e.g., hunting, fishing sight-seeing) or economically (e.g., directly--food, fur, pests of man, crops or timber products; or indirectly--recreational opportunities).

2. Species that are threatened or endangered.

3. Species that are important to the well-being of 1 or 2.

4. Species that are critical to the structure and function of the ecosystem.

5. Species that serve as indicators of an important change in the ecosystem.

The study of animals requires a knowledge of physiology, life histories, habitat requirements, behavioral patterns, and other factors controlling their distribution and abundance. Professional judgments are required to determine when and how an animal component should be studied. This manual can only provide a general process for designing a study and suggest potential literature resources that can aid the process. Imagination and ingenuity are usually required to design studies. Many existing techniques have been developed for large geographic areas and for large numbers of individuals. Estimating populations for small study areas requires a good local and regional perspective.

6.4.2.1 Mammals. Small mammals include insectivores (shrews) and small rodents (mice, voles, chipmunks, ground squirrels). They eat plants, seeds, and insects; they are important prey for raptors, foxes, coyotes, and other carnivores; they distribute seeds; they modify the physical properties of surface soils; and they may be pests and disease carriers.

In grasslands small mammals are generally more important to soil modifications and nutrient cycling than they are in woodland communities. In shrublands and woodlands, small mammals influence vegetation successional rates and trends by dispersing seeds. Because small mammals are often restricted to small home ranges, they experience environmental variations in a given area and may be useful indicators of subtle environmental changes over fairly long periods of time, such as chronic effects of energy development.

Medium-sized mammals include lagomorphs (rabbits and hares), tree squirrels, marmots, prairie dogs, porcupines, muskrats, beavers, weasels, skunks, badgers, raccoons, foxes, and bobcats. Most medium-sized mammals are important recreationally as game species (e.g., cottontail) or economically as furbearers (e.g., muskrats, beavers, bobcats) or as pests (e.g., porcupines).

Large mammals include domestic animals, mule deer, white-tailed deer, elk, moose, pronghorn, mountain sheep, mountain goat, mountain lion, black bear, grizzly bear, and coyote. Domestic animals, particularly cattle, sheep, and horses, range so widely over western energy-development areas that they may be not only the most important economic resource, but also the most important large mammal element of ecosystem structure and function. Most of the other large mammals are important economically, recreationally, and aesthetically. Game species may generate a large economic income from license sales and procurement of services and goods. In some areas the big game animals seriously affect crops or are predators of livestock.

Methods. Methods for measuring parameters of mammalian populations depend on the size and behavioral characteristics of the animal as well as the habitat within which it is found. There are bascially two classes of measurement methods: direct and indirect. Table 6-3 identifies standard references for estimating mammal populations. Table 6-4 is an expanded list of references that can be used when more detailed information about sampling populations is desired. Use this table in conjunction with Appendix C, the Annotated Bibliography, to determine which references discuss which methods. For convenience, mammals have been categorized as small, medium-size, and large.

Designing a study usually involves a preliminary site survey to determine what habitat types exist and what indirect signs of mammals can be found (e.g., tracks, droppings, rubbings). Use the results of this survey with the conceptual model to identify the species or types of mammals that are most important to study and to select the general approach to studying them. Direct methods are usually more costly than indirect methods because they involve setting traps, long periods of waiting for direct sightings, or large numbers of observers, as in big game drives. Removal trapping, as contrasted with nonremoval trapping, can sometimes change the population structure of the small mammal community for varying lengths of time. Even nonremoval trapping can result in some deaths and behavioral changes in a population. Indirect methods, such as pellet counts and track counts, are often difficult to calibrate to actual animal numbers.

Various removal-trapping techniques are commonly used to estimate species composition, population density, distribution, biomass, age ratios, and sex ratios of small mammals. Snap-traps are generally most efficient. If small mammals are important on a particular study site, however, an experienced professional should be involved in designing the program because of the great variation among methods and the species they work best for. Susceptibility to being trapped varies widely among species and with season. These differences can influence estimates of species composition, diversity, density, distribution, and home range.

Medium-sized mammals tend to be most active at night or in twilight, and they are otherwise secretive in their habits. Direct techniques include roadside counts, trapping, aerial counts, time-area counts, and night-lighting. Indirect techniques include scent stations, track counts, pellet group counts, and den, nest, lodge, or other home counts. Cottontail and jackrabbit populations are commonly estimated by roadside counts at night with a spotlight. In open country foxes have been counted by aerial censuses, but the best results for predators as a group have been associated with scent or bait stations. The number of homes (dens, lodges, houses, nests) reflect abundance of many

Table 6-3. Standard ecological attributes, parameters, methods, and references for evaluating mammalian components of the ecosystem. Numbers refer to references listed in Table 6-4.

			Small Mammals		Medium-Sized Mammals									Large Mammals						
ATTRIBUTE	PARAMETER	METHOD	General Sampling	Population	General Sampling	Cottontails	Jackrabbits	Hares	Tree Squirrels	Beaver	Muskrat	Red Fox	Black-Footed Ferret	General Sampling	Mule Deer	White-Tailed Deer	Elk	Pronghorn	Coyote	Bear
Species Composition	Name	Survey Techniques	26,48	26,48	47,54									47,54						
Species Diversity	Various Indices	Direct and Indirect Counts	26,48	26,48	47,54									47,54						
Relative Abundance	Qualitative Designation	Direct and Indirect Counts	26,48	26,48	47,54									47,54					39	
Density	Number/Unit Area	Direct and Indirect Counts	26,48	26,48	47,54	20,36	33,47	17,47	23,47	30,47	18,47	53,62		47,54	44,56	45,56	41,45	6,47	2,10	21,49
Sex Ratio	Males/100 Females	Direct Count	26,48	26,48	47,54	20,36	33,47	17,47						47,54	47	47	47			21,49
Age Ratio	Juveniles/Adult Young/Female	Direct Count	26,48	26,48	47,54	20,36	33,47	17,47						47,54	47	47	47			21,49
Frequency of Occurrence	Percent	Direct and Indirect Counts	26,48	26,48	47,54									47,54						
Distribution	Seasonal and Home Range	Direct and Indirect Counts	26,48	26,48	47,54	20,36	33,47	17,47				53,62	32,37	47,54	47	47	51			21,49

species, including marmots, prairie dogs, beavers, muskrats, and tree squirrels. Difficulties occur in calibrating the number of homes or other sign with the actual number of animals. Mark-recapture data sometimes are used, but most medium-size mammals are difficult to capture in live traps. Cottontails and squirrels have commonly been studied through live-trapping, but they often exhibit the same trappability problems as small mammals. Almost all predatory mammals are extremely trap-shy, and only steel-jaw traps are effective for foxes, raccoons, skunks, and bobcats. In the time frame of a baseline study, use home counts and possibly night roadside counts for most medium-size mammals and scent stations for predators.

Large mammal populations can be estimated directly from drive counts, aerial censuses, and strip censuses. Indirect methods include pellet group counts, track counts, and scent station counts. Shrubland and woodland areas that are relatively small and isolated can be censused by a drive count. For larger woodland areas and open country an aerial census can be conducted, although such censuses generally require ground-truthing or some sort of calibration. Strip censuses on foot or by vehicle are also commonly used. In a strip census, the observer counts all animals within a transect, which may be either of fixed width or of a width based on flushing distances.

All the direct-count methods are applicable to baseline studies, but they should be used only with full knowledge of their limitations. Indirect censuses commonly include pellet-group censuses for ungulates, scent-station or bait-station censuses for carnivores, and track counts for both groups. These methods provide an index of abundance and can be calibrated to reflect densities. Scent stations attract predators to a tracking station that has been scented with fermented egg, urine, or other attractants. The technique is most effective for coyotes. Pellet-group counts have been used most effectively for deer. Because of daily and seasonal variations in home range, these counts may not reflect true habitat use, but only that an animal defecated in a given location. The fact that pellet groups are not randomly distributed must be considered when designing the study and analyzing the data. Large sample sizes are commonly required for density estimates. Local experts may be needed to aid in adjusting experimental designs to site-specific needs.

Because mountain lions and bears seldom occur in large numbers a search of all habitats for sign (tracks, dens, scat) is probably one of the most effective techniques. Baiting of lions or bears can be used, but the technique provides little more information than the confirming of sign during general studies. Furthermore, baitings may actually attract animals into an area they do not normally frequent.

Summary and Comment. Small mammals are usually included in baseline studies on the questionable assumption that changes in their populations will accurately reflect man-induced perturbations to the ecosystem. However, the ability to predict impacts from one year's data is suspect on the basis of annual variability alone. It is even more suspect under the technical problems outlined above. Measurements of species composition and population density vary so widely under the influence of so many controlling factors that it is unlikely such parameters alone will ever be useful for more than point-in-time indices of conditions and trends. Semi-quantitative or qualitative data are probably adequate for most studies where the primary project-related effects are the clearing and alteration of habitats through construction and site

Table 6-4. References for methods commonly used for collecting and analyzing data on mammals for terrestrial baseline studies. Use the annotated bibliography (Appendix C) for specific information about each reference.

	Method	
	Field and Laboratory	Data Analysis
Small Mammals	General Sampling(a) 8,26,47,54,59	Same and also 63
	Population Studies 8,19,26,31,37,47,54	Same and also 48
Medium-sized Mammals	General Sampling 4,47,54	Same and also 19
	Cottontails 13,20,33,36,40,46,47	Same and also 19 and 54
	Jackrabbits 5,33,47	Same and also 19 and 54
	Hares 4,17,47	Same and also 19 and 54
	Tree Squirrels 23,27,47	Same and also 19 and 54
	Beaver 7,30,47	Same and also 19 and 54
	Muskrat 18,47	Same and also 19 and 54
	Red Fox 47,53,62	Same and also 19 and 54
	Black-footed Ferret 25,32,37	Same and also 19 and 54
Large Mammals	General Sampling 4,10,41,47,54	Same and also 19 and 29
	Mule Deer 3,4,9,11,12,19,22,24,28,42, 43,45,47,52,55,56,57,58	Same and also 19,29, and 54
	White-tailed Deer 4,9,11,12,16,22,28,34,43,45, 47,50,52,56,58	Same and also 19,29, and 54

Table 6-4 (Continued)

	Method	
	Field and Laboratory	Data Analysis
Large Mammals (Continued)	Elk 9,41,44,45,47,51	Same and also 19,29, and 54
	Pronghorn Antelope 6,47	Same and also 19 and 54
	Coyote 2,9,10,38,47,60,61	Same and also 19 and 54
	Bear 14,15,21,35,49	Same and also 19 and 54

(a) References

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60. Wolfe 1973
61. Wolfe 1974
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63. Pielou 1975

restoration. If sublethal effects (e.g., changes in reproductive rates as a result of heavy-metal emissions from a smokestack) are expected during operation of a facility, an intensive small-mammal study in the area of influence might be warranted. In general, such studies are limited in value because of problems with collecting data and in relating conclusions to impact predictions, mitigation, and monitoring. The state of the art for estimating species composition, density, and distribution is very weak. The conceptual model should provide guidance on studying small mammal populations.

Although medium-size mammals may be important, the number of individuals involved for most energy developments might not warrant intensive studies. Some reasonable indices are obtainable with low efforts of study, but only intensive studies can provide accurate quantitative data. However, relatively few quantitative studies of medium-size mammals have been conducted, and these have had numerous problems. The group is one of the most difficult to describe without data extending over several years. The recommended indices of abundance are useful for between-area comparisons but the data are not readily comparable with data from distant areas. Interpretation problems may also arise because of lack of precision and accuracy of existing census techniques and a generally deficient state of the art.

Because large mammals range over great distances, they are commonly studied over regions far larger than areas encompassed by a baseline study site. Many estimates of population parameters are based on hunting records and not on scientifically controlled direct or indirect studies, although sometimes hunting records are correlated or supplemented with direct or indirect observations. These supplemental studies, however, are generally geared to large areas and are not directly applicable to the smaller sites. A study for a smaller area must consider the regional and seasonal aspects of large mammal movements. Although these animals have habitat preferences based on environmental factors and behavioral orientations, these preferences may not be readily discernible.

Because large mammals are among the economically and ecologically most important groups to be affected by energy development, many members of the group are included in most baseline studies. Large mammals should be studied quantitatively when the impact is expected to be ecologically or economically significant. In such instances, the study program must reflect the total home range and habitat requirements for the population in order to provide the proper perspective for the site. The techniques for studying large mammals on a regional basis are generally effective, but questions about site-specific effects frequently fail to take the regional point of view. In general, large mammal studies that are restricted to a relatively small area, without reference to the surrounding region, are nearly useless.

6.4.2.2 Birds. Birds, too, can be conveniently grouped into three categories: small, medium-sized, and large. Small birds include all passerines, woodpeckers, swallows, and small shorebirds. The group does not include gamebirds, but does include many birds of aesthetic importance. In addition to being recreationally important, some species are economically important because of their role in insect control. Others, especially the blackbird group, can inflict considerable crop damage. Small birds tend to be omnivorous, eating invertebrates and buds, seeds, and fruits of plants. On occasion they help regulate insect populations, and they may modify plant succession by dispersing seeds.

Medium-sized birds include doves, quail, grouse, pheasant, waterfowl, gulls, terns, and other birds of this size. Most species within the group are economically important as gamebirds, and all are considered by many to be aesthetically interesting. Waterfowl are often economically important as crop destroyers. Many upland gamebirds and waterfowl are herbivorous and tend to exploit food resources opportunistically; if grain crops are available they will utilize the crop.

Large birds include raptors, geese, cranes, herons, ibis, turkeys, and other birds of similar size. Geese, cranes, and turkeys are important as gamebirds, and all large birds are recreationally important because of their aesthetic value. Geese can also be important as crop destroyers and as important ecosystem components when migrating or wintering population densities are high. Raptors, which are aesthetically important, include several threatened, endangered, or ecologically unique species.

Methods. As in the case of mammals, methods for measuring parameters of bird populations depend on size and behavioral characteristics as well as the habitat in which the birds are found. Both direct and indirect methods are used. Table 6-5 identifies key references for measuring different types of birds, and Table 6-6 provides an expanded list for more detailed studies. Appendix C provides further information about many of these references.

Studies of small birds generally use direct techniques, some of which are the whole-area count, time-area count, and strip count. Although more suitable for larger species, the whole-area count method is sometimes modified to map small breeding birds. The technique is useful only during breeding season, however. The time-area count is used to estimate the number of birds within a given radius for a specific time period. Time-area counts are useful in dense vegetation, such as shrublands and woodlands, and where vantage points are available, such as along a lakeshore. Strip censuses are among the most common techniques for evaluating small birds. The width of strip transects is commonly based on a calculation using flushing distance. Strip transects are most effective for censusing nonflocking passerines in open cover types. Problems associated with strip censuses include errors in estimating distances, missed observations, multiple observations of the same bird, and unreliable conversion factors. Their advantages lie in their efficiency and applicability to all seasons. Standard bird road counts represent a simplification of more quantitative strip transect counts.

All small-bird census techniques are difficult because species vary in conspicuousness. Conspicuousness includes behavioral characteristics, habitat preference, and physical characteristics. Often data must be treated only as an index of abundance or trend because of limitations in techniques. Where quantitative data are needed, many replicates may be required to obtain the desired reliability.

Other program design considerations include cover requirements and daily and seasonal variations in distribution and activity patterns. Daily activity patterns for feeding, singing, resting, nest-attending, and other functions affect distribution and conspicuousness. Many small birds migrate during the spring and fall to fulfill their seasonal habitat requirements. Daily and seasonal variations in distribution and activity patterns require census programs that recognize these variations. Birds also use several vegetative

Table 6-5. Standard ecological attributes, parameters, methods, and references for evaluating avian components of the ecosystem. Numbers refer to references cited in Table 6-6.

			Small Birds			Medium-Sized Birds						Large Birds			
ATTRIBUTE	PARAMETER	METHOD	General Sampling	Breeding Bird Surveys	Mapping	General Sampling	Pheasant	Growse	Dove	Waterfowl	Gulls	General Sampling	Raptors	Turkeys	Cranes
Species Composition	Name	Direct and Indirect Census	16,30,38	16,37,48		33,45				33,51		33	10,36		
Species Diversity	Various Indices	Direct and Indirect Census	16,33 58	6,16,48		33,45						33			
Relative Abundance	Qualitative Estimate	Direct Count	16,30,38	16,30,37		33,45						33			
Density	Number/Unit Area	Direct Count	16,30	6,16,48		33,45	21,49	22,46	23,33	33,51	29	33	10,36	41,44	52
Sex Ratio	Males/100 Females	Direct Count					49	43		33				44	
Age Ratio	Juveniles/Adult	Direct Count								33					
Frequency of Occurrence	Percent	Direct Count	16,30,38	16,30 37,48		33,45						33			
Distribution	Mapping and Territories	Various Mapping Techniques			6,35,48			43					10,36		
Seasonal Occurrence	Preserve and Breeding Status	Direct and Indirect Census	16,30, 37,38, 48			33,45				33,51		33	10,36		

cover types, such as ecotones, fencerows, field borders, and other heterogeneous vegetation. Most study designs, however, require homogenous cover types to reduce the variability of estimate, so if only homogeneous cover types are censused for birds, a major segment of the bird population on a site may go uncensused.

Both direct and indirect techniques are used to study medium-sized birds. Whole-area count techniques work best in open habitats and for flocking species. Aerial censuses are commonly used for waterfowl because large areas can be censused in a short period. During the spring, general search techniques are used for locating sage grouse and sharp-tailed grouse strutting grounds, or leks. Once a lek is located, all individuals using the lek can be counted from a remote observation point. Pheasant and grouse are usually censused by strip-transect techniques. These techniques use flushing distances to calculate the strip width, but they must be modified for flocking species, such as waterfowl; these are better estimated by fixed-width strip transects, or by time-area counts, where vantage points of open areas are available (e.g., marsh, pond, lake). The method has been used successfully for waterfowl during breeding, migrating, and wintering seasons. It can also be used where birds are moving to and from various habitats, such as watering holes, roosting locations, and feeding grounds.

Indirect censuses of medium-sized birds include auditory indices and counts of nests, roosts, displaying grounds, and droppings. These types of counts provide indices of abundance but require calibration to convert them into density estimates. The auditory index has been used extensively on doves (cooing counts) and pheasants (crowing-cock counts). Auditory-count indices are usually not converted into population estimates. However, on small study areas, auditory counts can be treated as time-area counts if the direction and distance of responding birds is recorded. One of the main problems of quantifying auditory indices is that of separating individuals. Other indirect counts are generally nonquantifiable. Thus, if a species is important, use direct counts, wherever possible.

Direct counts are also the primary methods for studying large birds. Because many are relatively sparse (e.g., raptors) or are flocking birds of open habitats (e.g., geese, herons, and cranes), whole-area counts can be used. Whole-area counts of raptors require traversing all potential habitats and recording direct observations of birds and nests. Aerial counts, which are commonly employed on large study areas, also provide an index of abundance for off-site populations. Resting and feeding areas can be evaluated by using a time-area count or using a vantage point to estimate the whole group. Because most large birds are conspicuous, their locations and numbers can usually be estimated, especially with the aid of local experts. Raptors, the more secretive of the group, may require intensive searches to locate nesting areas.

Indirect techniques, such as counting nests, droppings, pellets (undigested, regurgitated food from raptors), and feeding areas, provide valuable information that can be used to design direct counts. For turkeys, auditory indices have also been used during the breeding season.

Summary and Comment. Bird populations are highly variable in size and behavioral characteristics, and techniques for studying them must be suited to

Table 6-6. References for methods commonly used for collecting and analyzing data on birds for terrestrial baseline studies. Use the annotated bibliography (Appendix C) for specific information about each reference.

	Method	
	Field and Laboratory	Data Analysis
Small Birds	General Sampling[a] 5,8,16,24,27,30,33,35,37,38,56	Same and 13 and 45
	Breeding Bird Surveys 1,5,6.14,16,20,24,27,28,30,34,35,37,47,48,56,59,60,61	Same and 13 and 45
	Mapping 6,20,35,47,48	Same
Medium-sized Birds	General Sampling 2,33,39,45	Same and 13
	Pheasant 1,2,8,15,16,22	Same and 13 and 45
	Grouse 2,19,22,33,43,46,53,54,55	Same and 13 and 45
	Dove 7,23,33	Same and 13 and 45
	Waterfowl 2,4,11,25,26,31,33,42,51	Same and 13 and 45
	Gulls 29	Same and 13 and 45
Large Birds	General Sampling 33	Same and 13
	Raptors 9,10,17,18,36,40	Same and 13
	Waterfowl See "Medium Birds"	Same and 13
	Turkey 41,44	Same and 13
	Cranes 52	

Table 6-6 (Continued)

(a) References

1. Albers 1976
2. Anderson et al. 1976
3. Baxter and Wolfe 1973
4. Bennett 1967
5. Berthold 1976
6. Best 1975
7. Blankenship et al. 1971
8. Brewer 1972
9. Brown 1974
10. Craighead and Craighead 1969
11. Diem and Lu 1960
12. Diem 1976
13. Eberhardt 1971
14. Emlen 1971
15. Emlen 1974
16. Emlen 1977
17. Enderson 1965
18. Enderson 1970
19. Evans and Gilbert 1969
20. Franzreb 1976
21. Gates 1966
22. Gates et al. 1968
23. Gates and Smith 1972
24. Graber and Graber 1976
25. Hammond 1970
26. Hopper 1967
27. Howell 1951
28. Jarvinen and Vaisanen 1975
29. Kadlec and Drury 1968
30. Kendeigh 1944
31. Martinson and Kaczynski 1967
32. Nelson et al. 1962
33. Overton 1971
34. Peterson 1975
35. Porter 1974
36. Postupalsky 1974
37. Robbins and VanVelzen 1969
38. Robbins 1972
39. Robinette et al. 1974
40. Rusch et al. 1972
41. Sanderson and Schultz 1973
42. Sauder et al. 1971
43. Scott 1963
44. Scott and Boeker 1972
45. Seber 1973
46. Sisson 1976
47. Stewart and Kantrud 1972
48. Svensson 1972
49. Swope 1967
50. U.S.F & W S and Canadian W S 1977
51. Walkinshaw and Wing 1955
52. Wallestad and Schladweider 1974
53. Wallestad 1975
54. Weber 1975
55. Wiens 1969
56. Wiens 1974
57. Pielou 1975
58. Enemar and Sjostrand 1967
59. Robbins 1970
60. Svensson 1974

the particular type of bird. Small-bird studies, for instance, should focus on breeding populations except in cases where migrating or wintering birds tend to concentrate. For small birds, collect data that confirm presence or absence within the study area and its various habitats. Determine indices of abundance for important species or groups, such as seed-eaters, warblers, etc. Samples should be large enough to make at least qualitative comparisons between habitats. Data summaries should also reflect the specific use(s) of a habitat by birds. Judgments must be made on habitat suitability and adequacy for important bird species or groups. Habitat importance is usually considered highest for nesting habitat, and for many sites the breeding season may be the only important period in which to study small birds. Mapping is used widely for breeding birds. One of the main problems of all bird-censusing techniques is the lack of comparability of data between species and between habitats. Small bird studies should be more community-oriented and less species-oriented in order that their importance to the ecosystem might be better described.

Medium-sized birds include many recreationally important species. Numerous techniques have been developed by state and federal wildlife agencies for gamebird studies. For many regions of the West, censusing techniques have been refined, and historical data may be available for large study areas. Many census techniques developed by state and federal wildlife agencies for medium-sized birds are highly refined and may be applicable to the study area. State or federal data may be useful for designing your study or for comparing with your results. Breeding-season data on birds of this size are the most important for baseline studies; displaying areas, nesting areas, and brood habitat are necessary elements of breeding habitat. If migrating or wintering birds congregate on or near the site, estimate their numbers from a regional perspective. Much of the data will probably be most usefully interpreted as trends or indices. Absolute density estimates are time-consuming and often not feasible. Many of the medium-sized birds occur in relatively low densities, and for this reason it is difficult to obtain statistically verifiable results.

Large birds are a recreationally important group. Their numbers are best estimated through a whole count based on land and/or aerial counts of important habitats. Habitat availability is most critical for breeding birds; at other times of the year, large birds are less vulnerable to disturbances. The home range of large birds will generally include more than the proposed development area, and this additional area must also be evaluated. Breeding-bird density generally is low because of large territory requirements. Interpretations of breeding bird data should include evaluations of numbers present, habitat use, and future population potentials. Spring and fall populations of most large birds are highly transient, and population levels can vary greatly. Unless the study area is a wintering or staging area, the concentration of birds at a given spot during transitory periods is of relatively short duration. During winter, large numbers of raptors and geese winter in various regions of the West, and an individual site may receive high use by feeding or resting birds. Because of the importance of large birds, their presence should be at least qualitatively evaluated regardless of population abundance.

6.4.2.3 Reptiles and Amphibians. In most ecosystems, reptiles and amphibians are potentially important to the food chain. With the exception of California, no federally threatened or endangered species of reptile or amphibian occurs in the western states. At present, reptiles and amphibians are not intensively sampled in baseline studies because their economic, recreational, and ecological importance has not been clearly demonstrated at this time.

Methods. Reptiles and amphibians are commonly sampled by general habitat searches, pit-trapping, and strip transects (Table 6-7). Collections are often difficult because species may be highly localized, nocturnal, seldom encountered on the surface of the ground, or seasonal. Specific data on locality and times of activity are needed to sample reptiles and amphibians effectively.

The ideal time for sampling is spring, when amphibians congregate at breeding pools. During summer many species of frogs and toads are semiterrestrial, nocturnal, and widely dispersed, and they are dormant during the winter. Breeding pools can easily be located by the loud mating calls of male frogs and toads. Night sampling with headlights, dipnets, and tape recorders can provide estimates of relative abundance of amphibians in the area. Short-term, mark-recapture studies at these sites can provide quantitative estimates of breeding population sizes, and longterm, mark-recapture studies can be used to estimate the turnover rate of breeding adults. Because most amphibian populations exhibit high turnover rates in practically all age groups, studies designed to estimate turnover rate should rely on large sample sizes.

Qualitative information on lizards and snakes can be obtained by general habitat searches, pit-trapping, tracking, and night road-counts. Quantitative information on population densities has been gathered in many studies of lizards. Mark-recapture studies have been conducted using pit traps. Because lizards are commonly active during the day, they can be counted along strip transects. Snakes are more difficult to study because of their secretive nature, nocturnal activity pattern, frequent periods of inactivity, and long life span. General habitat searches and night road-counts are most commonly used for snakes. Turtle traps, basking counts, and opportunistic observations are the best methods available for determining the relative abundance of turtles.

Summary and Comment. In general, reptiles and amphibians are not considered important for most baseline studies. Sufficient information on species composition of reptiles and amphibians can usually be obtained from habitat searches and range maps. If an endangered or threatened species of herpetofauna is identified as present (or potentially present) on the site, comprehensive studies should be considered. Commonly occurring reptile and amphibian species might also deserve special studies in certain ecosystems if they are found to be important to the well-being of another species that is recreationally or economically valuable, threatened or endangered, or critical to the structure and function of the ecosystem. Although herpetofauna can be important to the food chain, determining how they are used as food by predators is not generally feasible. The nonquantitative data usually collected on reptiles and amphibians provide information on species presence and distributions. If quantitative information is necessary, methods are available (although time-consuming and costly) to determine the density, sex ratio, age ratio, relative abundance, and frequency of occurrence for most species of lizards, frogs, and toads. No methods are currently available, however, to provide meaningful quantitative data for snake and turtle populations.

Table 6-7. Standard ecological attributes, parameters, methods, and references[a] for evaluating herpetofaunal components of the ecosystem. A more general and comprehensive list is presented in the bottom half of the table.

ATTRIBUTE	PARAMETER	METHOD	General Sampling	Frogs and Toads	Salamanders	Lizards	Snakes
Species Composition	Name	All Methods	7,10,11	10,11	10,11	10,11	10,11
Relative Abundance	Qualitative Estimate	Pit Traps, Transects	7,8				
Density	Number/Unit Area	Mark-recapture	5,8				
Sex Ratio	Males/100 Females	Pit traps, Transects	5,8	14			
Age Ratio	Juveniles/Adult	Pit Traps, Transects	5,8	14			
Frequency of Occurrence	Percent	Pit Traps, Transects	7,8				
Distribution	Mapping Home Range	Searches, Mark-recapture	7	6		9	

Other References

Field and Laboratory Methods	Data Analysis
General Sampling - 1, 5, 7, 8, 10, 11	Same
Frogs and Toads - 4, 6, 7, 10, 12, 14	Same, and also 5 and 8
Salamanders - 3, 7	Same, and also 5 and 8
Lizards - 2, 7, 9, 10, 12	Same, and also 5 and 8
Snakes - 7, 10 11	Same, and also 5 and 8

Table 6-7 (Continued)

(a) References

1. Ashton 1976
2. Ballinger 1976
3. Burton and Likens 1975
4. Calef 1973
5. Eberhardt 1971
6. Kramer 1973
7. Porter 1972
8. Seber 1973
9. Simon 1975
10. Stebbins 1954
11. Stebbins 1966
12. Tinkle and Hadley 1975
13. Tordoff et al. 1976
14. Turner 1962
15. Wilber 1975

6.4.2.4 Invertebrates. Terrestrial invertebrates are potentially important both ecologically and economically. Ecologically they serve as herbivores and carnivores and as prey for vertebrates. They are also important pests of natural and cultivated plants and of wildlife, domestic animals, and humans. As individual species, invertebrates are generally not important, but as a group they contribute materially to the structure and function of ecosystems.

Methods. Direct and indirect census techniques are used for invertebrates. Most direct techniques use trapping devices, such as sweep nets, sampling enclosures, vacuum collectors, pitfall traps, and Berlese funnels, with numerous modifications to each type of trap, as well as qualitative methods. Bait or lights can be used to attract invertebrates. The technique selected depends on habitat type and species present. Table 6-8 contains a partial list of the vast literature on sampling and analyzing invertebrate populations.

Although techniques have been developed for a host of different species and habitats, it is difficult to collect data that accurately reflect each important species within each habitat, and which are comparable between habitats. Population numbers within a habitat fluctuate daily, seasonally, and annually as a result of changes in activity patterns, life stages, and population dynamics. The short generation time of many invertebrates allows them to respond quickly to environmental changes, such as food availability, climatic changes, predation, and pesticides. Population levels change rapidly, and even genetic characteristics of the population can be altered. The rapid population fluctuations and lack of accuracy in measuring those changes has restricted many baseline studies to qualitative data and indirect measures.

Indirect measures of invertebrates include observations of plant damage, animal damage, infection of plants or animals with diseases transmitted by invertebrates, nests, hives, and the abundance of predators that depend on invertebrates. Some indirect measures serve as indices of abundance. In many situations it is more productive to assess indirect evidence of species presence and to rely on local experts for regional and historical data.

Summary and Comment. For most baseline studies, qualitative evaluations of important invertebrate populations and their use of habitat are all that are needed. Because of difficulties in quantification, indirect indications of presence and abundance are often more useful than direct investigations. Plant damage, animal health problems, abundant insect-eating birds, and other such indicators provide indirect measures of abundance for most important invertebrates.

Studies of invertebrate populations often fail to provide meaningful data during a baseline study. Short generation times, the diversity of species, and the number of roles invertebrates play in ecosystems cause severe problems in sampling and statistical analysis. Some quantification techniques and indices of abundance have been developed for key pest species, but methods for studying nonpest species and interrelationships between species are poorly developed. The time required to collect quantitative data by present methods and the value of these data in terms of predicting impacts do not often warrant such studies. In most situations confirmation of pest presence and evaluations of present damage are more meaningful than studying the populations. Local experts can be invaluable in helping to determine which invertebrate pests are present and in providing information on their history in the area.

Table 6-8. Attributes, parameters, methods, and references for studying invertebrates in ecological baseline studies.

Attribute	Parameter	Method	Reference(a)
Species Composition	Name Percent	All Direct Methods	11,15
Density	Number/Unit Area	Berlese Funnel	10,14,15
Biomass	Kilograms/Hectare Pounds/Acre	Berlese Funnel Vacuum Collector Sampling Enclosures	1,11,15
Frequency	Percent	All Direct Methods	11,15
Distribution	Location	All Methods	7,11,15

(a) References for methods commonly used in the collection and analysis of data on invertebrates for terrestrial baseline studies.

1. Bender et al. 1972
2. Chew 1959
3. Dietrick et al. 1959
4. Dondale et al. 1971
5. Gist and Crossley 1973
6. Green 1969
7. Knight 1966
8. Mason and Blocher 1973
9. Matthews and Matthews 1971
10. Mehhinick 1963
11. Reed 1972
12. Rickard and Haverfield 1965
13. Riechle et al. 1973
14. Seber 1973
15. Southwood 1966
16. Turnbull and Nicholls 1966

6.4.3 Decomposers (Soil Microorganisms)

The soil contains a complex community of microorganisms whose major role is to decompose and mineralize organic matter that accumulates on or under the soil surface. This process is indispensable to efficient energy flow within an ecosystem. Bacteria and fungi are the major contributors to this process. Only recently has research revealed the extent to which these organisms participate in energy flow. In grasslands, where plants produce net dry matter at the rate of 1 $kg/m^2/yr$, no more than one-third of this total is consumed by herbivores. The remainder goes to the decomposer community in and on the soil, where fungi, whose biomass exceeds that of all other microbes, effectively reduce most of this plant matter within a single season. Soil microfauna, too, are very important in reducing organic particle sizes and transporting these particles into the soil, where they are acted upon by the decomposers.

Other essential roles performed by soil microorganisms include fixing atmospheric nitrogen (bacteria and blue-green algae), transferring water and minerals into plant roots (fungi as mycorrhizae), and causing plant and animal disease. The metabolic byproducts and remains of soil microbes, along with parent material, develop the fertility, morphology, and physicochemical properties of the soil.

The destruction of the intimate plant-microorganism association and/or the disruption of the ecosystem processes cited above are considered to be the likely changes (perturbations) resulting from energy-development activities. These disruptions can be produced by changes as simple as alteration of soil structure and profile or as complex as the accumulation of toxic elements in the organic matter. Recent research has already shown that bacterial and fungal populations can be adversely affected by atmospheric pollutants entering the soil (States 1978). Trace-element accumulation in soil is toxic to soil microflora (Jordan and Lechvalier 1975). The decomposition activity of soil microbes is directly correlated with density, species diversity, and respiration of microbes (Witcamp 1966). Therefore, these attributes may be studied and used as indicators of environmental perturbation. The extent to which the environmental perturbations modify the decomposition process can be evaluated and incorporated as a part of the impact matrix.

Methods. Techniques for examining soil microorganisms are generally based on direct observations, plate counts for isolation and identification of species, and evaluation of selected attributes of the decomposer community (Table 6-9). Depending on the organisms and the objectives of the study, techniques based on one or more of these approaches may be employed. The selection of the appropriate methodology usually requires the professional judgment of an experienced microbial ecologist or soil biologist.

Initially decisions must be made regarding sample numbers, sizes, site locations, and sample analyses. These decisions must be based on the nature of the study site, variability in the edaphic environment, the methods and facilities available, and the objectives of the study. Often a quick, preliminary study can be conducted to evaluate these factors and thereby greatly increase the efficiency and value of the final study.

Direct observation techniques are most useful for the larger members of the soil community, the microfauna. Many methods have been developed including

Table 6-9. Standard ecological attributes, parameters, methods, and references[(a)] for evaluating soil microorganisms.

ATTRIBUTE	PARAMETER	METHOD	General Sampling	Mycorrhizae	Plant Disease
Species Composition	Name-list	Survey Methods	6,8	7	3,12
Density	Numbers/Gram of Soil	Various Sampling Methods	1,6		
Biomass	Weight Volume	Various Sampling Methods	6,8	7	
Frequency of Occurrence	Percent	Various Sampling Methods	1,6	7	3,12
Decomposition	Rate	Respirometry	5,10		
Nitrogen Fixation	Rate	Acetylene Reduction	13		

(a) References for methods commonly used in the collection and analysis of data on soil microorganisms for terrestrial baseline studies.

1. Christenson 1969
2. Halverson and Ziegler 1933
3. Johnson and Curl 1972
4. Kent 1972
5. Klein et al. 1972
6. Parkinson et al. 1971
7. Phillips and Hayman 1970
8. Phillipson 1970
9. Rose and Miller 1954
10. Rosewall 1973
11. States 1978
12. Tuite 1969
13. UNESCO 1969

the use of chemicals to drive them to the soil surface, and funnel-sedimentation techniques to determine species frequency and abundance in soil samples.

Baiting techniques or counts of colony development on agar medium are often used to study bacteria, fungi, and actinomycetes. Various general and selective media have been used for the growth of these organisms. The media can be tailored to foster the growth of specific groups or individual organisms selectively. The standard preparation of soil samples for colony counts involves sieving the soil sample followed by serial dilution and plating of the sample on growth media. This process releases the reproductive and vegetative units of the fungi, bacteria, and actinomycetes from the soil sample. Both the composition of the growth medium and the environment in which incubation takes place are critical factors that determine which species will grow and how fast they develop. Plating techniques can be employed for determining species diversity and species abundance. However, they must be used with some caution in population studies because of the possibility that spore-producing species will be overly represented in the dilution plates. Once recognized, this problem can be corrected.

Characterization of the nature and extent of a physiological attribute, such as decomposition or nitrogen fixation, generally involves a more complicated application of microbiological techniques. In many cases, isolation, culture, and direct measurement of physiological processes are required. The techniques for these tests are generally well-defined and available, but their sensitivity and resolution are quite variable. Again, it is recommended that a soil microbiologist be consulted before attempting to measure physiological parameters in soil systems.

Summary and Comment. In an ecological baseline study, the definition of soil microbial communities and their contribution to the ecosystem can be of great value. Where it is anticipated that toxic elements or pollutant gases may be released and accumulated in parts of the soil environment, the plant-microorganism relationships, with time, may indicate a serious environmental perturbation that may be difficult to overcome or mitigate. If extensive revegetation will be required in the impacted area, an understanding of how soil microorganisms can maintain existing and/or introduced plants can greatly facilitate the reestablishment of vegetation on that site. For instance, mycorrhizal infection is essential for the survival of some trees and herbaceous plants in coal spoils (Daft et al. 1975).

The techniques developed to examine the presence and activities of soil microorganisms are numerous. Make sure that the technique used to collect data is appropriate and consistent with the study objectives. Evaluate qualitative data in the light of the isolation technique and its inherent selectivity. Obtain quantitative data with the dilution-plating technique, whereby community composition and species abundance can be defined and compared. However, be careful when evaluating the abundance of microorganisms in soil: Although data may be compared in a relative sense, their relationship to the absolute population size and microbial processes in the soil is difficult to determine. When questions arise, seek the assistance of a professional soil microbiologist.

6.5 AQUATIC SYSTEMS

6.5.1 Introduction

Our interest in aquatic environments centers on quality or quantity - both of the water itself and/or the organic production that occurs within it. The desire to have water in sufficient quantity and quality to satisfy a domestic water supply, an industrial use, or agricultural purposes is clear, so we focus attention on the kinds and amounts of salts and other substances dissolved or suspended in the water.

When the primary interest is in the ability of a body of water to produce fish or other animals for food or sport, or simply to provide a pleasant environment for recreation or aesthetic enjoyment, concern for quality and quantity of organic production becomes as great as, or greater than, that for dissolved substances. In the last analysis, the distinction between concentrating attention upon either water or biota disappears because of their intimate interrelationships. As an example, the kinds and quantities of salts affect the quantity, and perhaps the quality, of biota within a body of water, and in turn, the kinds and quantities of biota in that body will influence the quality and uses of the water.

The capacities for fresh waters, either standing or running, to produce and support plants and animals range widely and are affected by many abiotic and biotic factors. In physically harsh environments, factors that limit production both quantitatively and qualitatively are usually evident. Consider, for example, an alpine lake that is ice-covered ten months of the year. The lake receives water low in dissolved nutrients because the drainage is from highly insoluble igneous rocks. This lake is basically limited in organic production by low temperatures, lack of nutrients, and perhaps other, less-obvious causes. A fishery biologist walking beside a shallow prairie stream that flows over a substratum of loose shifting sand, and whose banks indicate the occurrence of alternate flooding and extreme low water, knows why few fish, or none are produced there. Conversely, the luxuriant stands of macrophytes or dense blooms of algae in a pond receiving domestic sewage effluent are not difficult to explain.

These are obvious examples. For the great majority of streams and lakes, total organic production is the result of many factors operating in subtle ways. However, even in cursory baseline studies, you must attempt to define factors that appear to limit aquatic organic production within the baseline area.

Generally, aquatic systems that have high aesthetic appeal rank low to moderate in producing biota. The concept of quality of organic production is highly colored by individual bias. For instance, anglers as a group might agree that water with fish is better than water without, and that game species are more desirable than minnows, rough fish, and other non game species. It is highly unlikely that all would put the same species in each category, and it is very certain that no consensus could be reached as to the "best" game fish. Probably very few people would rate as "desirable" the blue-green algae that, in sufficient numbers, turn lakes turbid, produce a soupy appearance, and develop into smelly scums and windrows on shore.

Some of the most perplexing questions in the management of aquatic environments attempt to decipher why organic production has followed a particular path, culminating in one result in one lake or stream, and used another route to arrive at a different result in another, seemingly similar lake or stream. Our state of knowledge is not developed sufficiently to define all requirements for the various species of aquatic organisms in their various life stages.

Most concern about energy developments near aquatic areas is that impacts may bring about changes, usually believed to be undesirable, in kind or amount of organic matter in the affected waters. Potential changes in quantity are much easier to estimate than changes in quality. Subtle changes that tip the delicate balance of competition, affect mortality at a critical life stage, or modify critical behavior are exceedingly difficult to predict *a priori* and may be hard to discern *a posteriori*.

We characterize qualitative organic production by sampling the various components of the system and identifying the plants and animals obtained. The end result is a list of species. Though not too useful for predicting impacts, the list is frequently considered an end in itself. However, a carefully prepared list of species interpreted by an expert biologist can convey useful information.

Because of ecosystem dynamics, it is much harder to characterize quantity of organic production than quality. Individuals are born, they grow, they reproduce, and they die or leave the system; individuals may enter from other systems if pathways are available. Thus numbers of individuals and total biomass constantly change at greatly varying rates. These rates are very difficult to measure directly and satisfactorily under field conditions with state-of-the-art methods. Where protoplasm is being formed, it is appropriately referred to as *productivity*.

When productivity cannot be estimated directly, an indirect approach is through standing crop. This is simply the amount of biomass on hand at the moment of sampling. Standing crop is the net difference between processes of reproduction, growth, and immigration, which tend to increase the crop, and of death, grazing, emigration, sinking, etc., which tend to decrease it. Although standing crop is of interest, alone it does not reveal how rapidly the biological processes that determine it are operating. A large crop can result from a low rate of production combined with very low rate of mortality; conversely, a small standing crop may result from low rate of production and low rate of mortality or high production subject to high mortality.

The characterization of quantity and quality of organic production in aquatic environments is beset by seasonal and year-to-year variations. Seasonal variations in organisms are most pronounced in short-lived species. The species of algae or rotifers in the summer plankton are usually quite different from those present in the winter or spring plankton. Total amounts also differ.

Such seasonal variation is much less evident for longer-lived species than for short-lived forms. Although numbers and, to a lesser extent, biomass of fishes or macrophytes change seasonally, the species composition does not change, except for migratory species. Thus, qualitative sampling results can be markedly affected by the season.

Productivity may also exhibit seasonal variation, and standing crops of short-lived organisms will vary severely within a single year.

Year-to-year variations in productivity, standing crops, and total production are also commonplace. Long-term studies for the purpose of defining year-to-year changes in organic production essentially do not exist. Two-year comparisons are not unusual, but comparative data for longer spans are. A cursory examination of available data suggests that a biologist may reasonably expect the second year's data, whether on productivity, standing crops, or estimates of total production, to be within 50 to 200 percent of the first year's values.

In aquatic systems where only a few species dominate the community or system, methods of measuring populations and their well-being may offer the best way to assess baseline conditions. However, we are usually more interested in the overall condition of the system than in a few selected species, but to assess the individual well-being of all species is an enormous task. Therefore, indices that indicate overall conditions of communities or systems are usually economical and are ecologically valuable. "Clearly to attempt to devise sets of unique ecological indices for each of the common types of aquatic systems would be expensive folly. We seek indices most of which will be applicable to many if not most ecosystem types" (FAO 1976).

To aid the manual user in discriminating among parameters and in selecting methods appropriate to investigation of aquatic systems in his particular circumstance, we offer the following simplified approaches:

1) Emphasize the physical characteristics of abiotic portion of the system.

2) Focus on one or a few selected populations that are of special concern, i.e., commercial or game species.

3) Where possible, measure indices that reflect community or system conditions.

Because these approaches are over-simplifications, rarely would one be used exclusively of the others.

Perhaps the most fundamental distinction among surface freshwater environments are those of running vs. standing waters. Figure 6-1 suggests how to choose priorities among general approaches to investigating basic freshwater systems, based on the level of effort and scope of a baseline study. Low-level efforts might involve developing a baseline report from existing information with or without a site visit, or perhaps with one brief sampling excursion. High-level efforts would encompass two or more seasonal excursions to obtain site-specific sampling information. Use the figure to help decide how to obtain maximum useful information per unit of expense.

Level of Baseline Effort	Primary Aquatic System	
	RUNNING	STANDING
HIGH	I Physical Environment II Community/System III Selected Population	I Community/System II Physical Environment III Selected Population
LOW	I Physical Environment	I Physical Environment - Community/System

Figure 6-1. Decision diagram indicating priority of approaches to studying aquatic systems in two levels of baseline effort

Table 6-10 lists characteristics or indices that yield the most information per unit of effort when used in the approaches of Figure 6-1. Because of fundamental differences in running and standing aquatic systems, different physical characteristics are emphasized in each. Characteristics listed first under physical, represent the minimum amount of information needed in even a low-level baseline effort. Characteristics in the second group provide very useful information. They are highly desirable in low-level efforts and essential in high-level baseline studies. Chemical characteristics of both standing and running waters are similar.

Although the same types of communities tend to be present in standing and running systems, species composition in these systems differs markedly. Perhaps the most notable and fundamental biotic difference is the relative unimportance of plankton assemblages in running water. In Table 6-10, communities are ranked in order of the relative return of information per cost of sampling in general.

The table also shows that certain attributes are common to all communities in both standing and running water, i.e., regardless of community being studied, we are interested in diversity, standing crop, productivity, or distribution of the forms composing the community. Regardless of the kind of population, we are interested in vital statistics that indicate its structure, rates of increase, and rates of decrease.

The purpose of Figure 6-1 and Table 6-10 is to help the manual user select specific methods by focusing attention on those facets of the aquatic system under study that will likely yield the most information per dollar or unit of effort expended.

As an example, suppose that a baseline survey is required for a small stream in an area where coal is to be stripmined and that only one site visit plus existing information will be used in developing the baseline report. Figure 6-1 tells the investigator to concentrate on the physical aspects of the stream. Table 6-10 lists six items to receive special notice and several items of secondary importance. These factors are important because the physical characteristics of streams are what controls production of organic matter.

If the impact of the mining is expected to be large enough to require a year for gathering site specific data, we see from Figure 6-1 that in addition to physical environment, we should consider Community/System characteristics. Table 6-10 reveals that communities of macroinvertebrates and fish should receive priority over periphyton and macrophyte assemblages. Thus we might wish to devote most of our efforts to determining diversity and biomass of macroinvertebrates and distribution of macroinvertebrates and fish in space and time. If more intense sampling is warranted, one or two selected populations might be investigated.

In another example, suppose that a low level of effort is sufficient for a baseline survey of a 20-acre pond. Figure 6-1 tells us that effort should be about equally divided among Physical Environment and Community/System approaches. From Table 6-10 we further learn that five physical characteristics are essential. If only one sampling can be made (assuming no site-specific data), effort should be equally spread among the first four communities. If site-specific data are available, sampling can be used to supplement them and

Table 6-10. Characteristics or indices commonly measured in aquatic systems. See text for further explanation.

	Running	Standing
PHYSICAL		
Primary	Discharge	Area
	Current Velocity	Volume
	Substratum	Flushing Rate
	Temperature	Temperature Profile (Midsummer)
	Dissolved Oxygen	Dissolved Oxygen Profile (Midsummer and Midwinter)
	* * *	* * *
Secondary	Conductivity or Total Dissolved Solids	Conductivity or Total Dissolved Solids
	Alkalinity	Alkalinity
	pH	Major Ions
	Major Ions	pH
	Nutrients (Nitrogen, Phosphorus)	Nutrients (Nitrogen, Phosphorus)
	Suspended Load	Minor Ions
	Duration of Ice Cover	Light Penetration (Midsummer)
	Trace Elements	Duration of Ice Cover
		Trace Elements
COMMUNITY		
	Macroinvertebrates	Phytoplankton
	Fish	Zooplankton
	Peripyton	Macroinvertebrates
	Macrophytes	Fish
		Macrophytes

Diversity
Biomass
Productivity
Distribution in Space and Time

SYSTEM

Production/Respiration Ratio
Production/Biomass Ratio

POPULATION

Fecundity
Birth Rate
Mortality Rate
Growth Rate
Age Structure
Sex Ratios

fill in gaps. Attributes of biotic-community components cannot be well described on the basis of a single sampling effort, but diversity and magnitudes of biomass, at least at one moment in time, can be determined. Actually, profiles of temperature and dissolved oxygen taken in mid-summer or mid-winter may be quite revealing about the pond system in general.

At a higher level of baseline study where site-specific investigations are required in all four seasons of the year, we can estimate within-year variations in amounts and kinds of biota. More sampling, particularly over extended periods, better reveals community and system characteristics, and permits us to look in detail at selected populations. Production:respiration and production:biomass ratios are especially indicative of overall system conditions.

Choosing sampling locations is another important aspect of aquatic baseline work. Stations should represent all major habitats present in the area where impacts from the development are expected to occur. Where possible, sample in areas outside the expected impact area, but in habitats similar to those within it. These control sites provide: 1) comparisons to help evaluate results and give a regional perspective to sampling areas of expected impact, and 2) reference points in future monitoring efforts. Because of year-to-year natural variations in biological populations, before-and-after comparisons of baseline data and operational monitoring data are exceedingly difficult. Comparisons of data obtained simultaneously at control and impact areas may be more valuable and easier to interpret.

Select control sites carefully to ensure that they are, in fact, similar to the possible impact area and are free from disruptive influences or not otherwise subject to stresses not found on the control sites.

Statistics are valuable for evaluating seasonal and year-to-year variability in aquatic data. When even a few biological components are to be sampled, take replicates. You can then estimate variability and construct confidence limits about mean values.

For high-level studies replicate sampling is mandatory wherever the reliability of estimates is critical. However, the biologist must be prepared to accept more variability in his estimates than is normally encountered by physical scientists.

Finally, in establishing baseline sampling programs that will lead into subsequent comparisons, the biologist might wish to consider this admonition concerning aquatic ecological systems. "It follows therefore that no biological measure that we may wish to use for index purposes remains constant. The concept of 'baseline' is misleadingly oversimplified. Rather there are spectra of values which encompass the normal range of responses . . . .

"The significance of the existence of such background fluctuations is inversely proportional to the severity of any man-made stress . . . . The widespread and severe mortality that may result from a major tanker accident transcends all the subtleties and most of the extremes of natural causalities; but in assessing the effects of a new industrial or urban discharge misinterpretations could arise" (FAO 1976 p. 15).

These remarks are general and circumstances in any particular system may clearly indicate reordering of priorities. However, irrespective of kind of system or its individual characteristics, we should always make a determined effort to define the factors that are presently limiting organic production within that system.

In selecting specific techniques, you should be aware that the literature bristles with literally dozens of techniques useful in measuring aquatic parameters. Many techniques are only small modifications of widely used general procedures. This manual identifies methods that are commonly used in many freshwater habitats and that can be considered more or less basic, standard procedures.

Frequently a table will offer a choice of parameters. This is because there is often no best parameter for a particular attribute; there are only different parameters and you must decide which fits your situation, given the objectives of the particular project. Cited references provide more detail on particular methods.

Methods for studying aquatic ecosystems are presented in the same way as methods for terrestrial studies. The tables list major attributes and parameters for each broad class of components, together with references for field, laboratory, and data-analysis methods. In these tables, the attributes of abundance, biomass, diversity, indicator species and associations, and productivity are common to all the biological communities discussed. Some of these terms, which are defined in the glossary, are discussed briefly below.

In regard to determining abundance: "The shorter and more irregular the temporal fluctuation, or the larger the range of sizes and mobilities of the organisms present, the more difficult it is to devise reliable sampling programmes. Obtaining unbiased and highly precise estimates of abundance, for example, is always out of the question except for a small number of carefully selected life stages of a few species" (FAO 1976, p. 26).

Biomass is usually expressed as weight of organisms per unit volume or area. Diversity, a measure of complexity in the composition of communities, is useful in comparisons between communities and as an index of environmental conditions. The simplest measure of species diversity is the number of species of a given taxonomic group occurring in an area. Such a measurement does not consider the relative abundance of the species present, however.

Pie graphs that illustrate relative abundance of species or higher taxa, e.g., percentages of diatoms, blue-green and green algae, are often effective in conveying information. Numbers of species and numbers of individuals present are often combined in some manner to produce a diversity index. The more species present, and the more equal the population density of the species that are present, the higher the diversity index will be. If species counts are already available, diversity may be calculated with little trouble. An advantage of diversity values is in having a dimensionless number that permits inter-community comparisons. Diversity may be calculated from several formulas; Pielou (1975) discusses the theoretical bases for them. The principal disadvantages in using diversity measurements are choosing which formulas to use and interpreting the values that are calculated. Odum and Cooley (1976) suggest that workers uncertain about the meaning of diversity indices use profile analysis instead. There is no single, universally accepted measure of diversity, although Poole (1974) states that the number of species is the only truly objective measure of diversity.

Just as an indicator species may reflect certain environmental conditions in a particular area or habitat, particular grouping of species may form an indicator association. Such an association also indicates certain environmental conditions in a particular area or habitat.

6.5.2 Abiotic Factors

Aquatic communities exist in physical surroundings. They are impacted by and react with a broad spectrum of physical and chemical factors. Only factors of demonstrated importance in most waters are included here. The literature on chemical analysis is vast. Methods books for physical factors are fewer; and rarer yet are lucid, comprehensive accounts of the importance of abiotic factors to aquatic biota. Authoritative references for these specialties are cited in Table 6-11. Although both chemical factors and some physical factors are common to standing and running water, there are important differences. Thus, two sets of physical parameters are given in Table 6-11.

Physical, Standing Water. Knowledge of area and volume, besides being indicators of absolute size, are essential for quantitative estimates of total biomass and energy or materials balances. Flushing rate, the time required for an influent stream to replace the volume of a standing water basin, may range from days to dozens of years. Flushing rate is useful for evaluating possible retention time or build-up of pollutants or other materials reaching lake or reservoir basins. In general, rapid flushing tends to prevent accumulation of organic production and to retard productivity.

Temperature is extremely important in aquatic environments. In standing waters, temperature-density relationships largely determine if thermal stratification will occur. Temperature influences rates of chemical reactions both in the physical environment and in the physiological processes of organisms.

Turbidity, opaqueness of water, is conferred by suspended materials, such as silt or plankton. Secchi disk transparency is a field technique that quickly and easily yields an estimate of turbidity. Secchi disk transparency is related to light penetration. Light can also be measured directly by photometer. However, Secchi disk readings give an indication of depth of a photic zone, i.e., the depth to which algae perform most photosynthesis.

Ice cover seals lake surfaces from gaseous exchange with the atmosphere and reduces light penetration, especially when the ice is snow covered. Thick prolonged ice cover promotes winter kill in lakes in which considerable decomposition of organic matter by bacterial processes occurs.

Physical, Running Water. Discharge is the product of stream channel cross-sectional area (bounded by water surface and wetted substratum) and mean velocity of the water. Instantaneous and annual discharges are of interest. Pattern of discharge throughout the year is also important in evaluating streams as a habitat for organisms.

Table 6-11. Attributes, parameters, and references to methods for the abiotic component of aquatic systems. Numbers in method columns refer to work cited at foot of table. These works contain specific information as indicated.

		Method		
Factor/Component	Attribute	Field	Laboratory	Data Analysis
Physical, Standing Water	Area	5		2
	Volume		5	2
	Flushing Rate			2
	Temperature	3,4,5	3	2
	Turbidity	3,4,5	3,5	2
	Ice Cover			2
Physical, Running Water	Discharge	4,5,8	4	8,9
	Current	5,8		8,9
	Substratum	4,5,8	4,5,8	8,9
	Temperature	3,4,5		9
	Turbidity	3,4,5	5	9
	Ice Cover			9
Chemical	Conductivity	1,7,10	1,7,10	1,2,6,7,9
	Major Ions	1,7,10	1,7,10	1,2,6,7,9
	Nutrients	1,4,7,10	1,4,7,10	1,2,6,7,9
	Dissolved Oxygen	1,3,4,5,7,10	1,3,4,5,7,10	1,2,6,7,9
	pH	1,3,4,5,7,10	1,3,4,5,7,10	1,2,6,7
	Trace Elements	1,7,10	1,7,10	1,2,6,7

1. American Public Health Association 1971
2. Hutchinson 1957
3. Lagler 1956
4. Schwoerbel 1970
5. Welch 1948
6. Hem 1970
7. Golterman 1969
8. Leopold et al. 1964
9. Hynes 1970
10. U.S. Environmental Protection Agency 1974

Current, or rate of flow, where animals and plants actually live is of great biological interest. Stalnaker and Arnette (1976) present a recent state-of-the-art review of methods for measuring stream flow and assessing aquatic habitats in streams.

Velocity and discharge are related to stream competency and capacity, i.e., size of individual particles that can be transported and amount of material transported. Conditions that promote erosion of, or deposition on, the substratum affect organisms living there. Plants and animals that live on or in the substratum exhibit strong preferences for certain types of substrata. Therefore, the substratum of a given stream signals to the investigator the kinds of organisms that he may expect to find.

Temperature and turbidity play roles in running water similar to those in standing water.

Ice on the surface of streams acts much as it does on lakes, i.e., sealing, or at least greatly retarding, gaseous exchange between water and atmosphere. However, streams in cold climates may be subjected to ice actions that do not have counterparts in the standing waters. "Frazil," or crystals of ice that form in supercooled water, may severely scour substratum and organisms dwelling there. Anchor ice forming on the substratum of supercooled streams may greatly disrupt substratum and benthos (Hynes 1970).

In regard to physical factors in running water, Hynes (1970, p. 383) writes ". . . such properties as temperature, depth, current speed, substratum, and turbidity . . . these are all important factors controlling the distribution . . . of the biota."

Chemical Factors. Conductivity is an estimator of total dissolved salts. Salinity of freshwater has physiological implications for the organisms that live in it. Freshwater plants and animals maintain salt content of internal fluids greater than that of most freshwaters at metabolic expense. There is, however, an upper tolerable level of salinity for each freshwater species. Although total salinity is important, the amounts and proportions of various dissolved salts are also important.

Based on abundance in freshwaters, the major ions are potassium, sodium, calcium, magnesium, sulfate, carbonate, bicarbonate, and chloride. Calcium bicarbonate is of special importance as a source of carbon dioxide for photosynthesis by many species of macrophytes and algae and as a buffer against rapid shifts in pH. Hutchinson (1975), Cole (1975), and Wetzel (1975) give accounts of the relationships of bicarbonate, carbon dioxide, and pH. Limnologists have long recognized that lakes poor in alkalinity, as an equivalent of bicarbonate, are usually poor in productivity.

Nitrogen, phosphate, and silica, are important as nutrients for the primary production that is the basis of many freshwater food webs. Phosphate is highly mobile and may occur in several different forms, but baseline data on these elements are helpful in determining factors that limit productivity.

Oxygen is necessary to the respiration of the vast majority of freshwater organisms and is of critical physiological importance. Oxygen is also an important constituent of the aquatic chemical milieu because of its reactions with other chemicals in the environment.

In standing and slowly flowing waters, dissolved oxygen can frequently be used as an indicator of system conditions. Oxygen is released into the water by photosynthesis of algae in the plankton and periphyton. It is removed by respiration of the biota. Several measurements of concentration of dissolved oxygen made over a 24-hour period may indicate whether photosynthesis or respiration is predominating. Because of aeration associated with turbulence, dissolved oxygen is not useful in determining photosynthesis/respiration ratios in rapidly flowing streams.

Subtle changes in nutrient input or additions of bacterially decomposable organic matter may be detected at the system level before they are detectable by chemical or population changes.

Hutchinson (1957 p. 575) wrote, "A skillful limnologist can probably learn more about the nature of a lake from a series of oxygen determinations than from any other kind of chemical data. If these oxygen determinations are accompanied by observations on Secchi disk transparency, lake color, and some morphometric data, a very great deal is known about the lake."

Rickert et al. (1976) demonstrate how depletion of dissolved oxygen, occurrence of trace metals, potential algal problems, and other factors that may create basin-wide water quality can be quantified and statistically evaluated through modeling techniques.

Burdens of trace elements either in the water or biota of an area are rarely well known at the time that a baseline study is completed. If there is reason to suppose that a particular energy development may add to background levels of trace elements, or if the development is to occur in an area known to be already under impact from effluents containing trace elements, then baseline data on trace elements should be obtained.

6.5.3 Phytoplankton

Phytoplankton is composed mostly of microscopic, single-celled algae that drift passively with water currents. The phytoplankters are the major primary producers in standing water and, as such, are at the base of many aquatic food chains and webs. Only in very slowly moving streams, do phytoplankters form a significant portion of primary producers in flowing waters.

The amount of phytoplankton and the species constituting it vary greatly throughout the year, particularly in temperate freshwaters. At a minimum, quarterly sampling is needed in order to yield site specific data. However, because of broad ecological requirements of many common species, the general qualitative composition of the phytoplankton is often similar among similar-sized bodies of water in broad geographic regions.

In addition to seasonal variation, quantities of phytoplankton vary within one body of water from year to year in response to variations in physical and biological factors. Annual variation is difficult to define without many years of data, thus comparisons of one or two years of baseline data with one or two years of postoperational data are usually meaningless.

Table 6-12 lists attributes of the phytoplankton component and parameters that are presently measurable. Five attributes are recognized, for which approximately ten parameters are commonly measured.

Table 6-12. Attributes, parameters, and references to methods for the phytoplankton component of aquatic systems. Numbers in method columns refer to works cited at foot of table. These works contain specific information as indicated.

Attribute	Parameter	Method		
		Field	Laboratory	Data Analysis
Abundance	Numbers	1,2,3,5,6,7,8,9,10	1,2,3,6,7,9,10	
Biomass				
Gravimetric	Weight		1,3,6,8,9,10	
Volume	Measure and Count		1,3,7,10	
Cellular Content	Carbon, Nitrogen, Silicon, Chlorophyll, ATP		2,3,6,7,8,9	9
Diversity	Identification, Count		1,2,10	2,4
Indicator Species and Associations	Identification			4,11
Productivity or Rate of Production	Dissolved Oxygen Production, Carbon 14 Uptake	1,2,3,7,8 9,11	1,2,3,7,8,9 11	6

1. American Public Health Association 1971
2. Environmental Protection Agency 1975
3. Weber 1973
4. Hutchinson 1967
5. Lagler 1956
6. Lund and Talling 1957
7. Schwoerbel 1970
8. Strickland 1960
9. Vollenweider 1974
10. Welch 1948
11. Wetzel 1975
12. Wood 1975

Abundance. Perhaps the most frequently used attribute to describe the phytoplankton is the number of cells or individuals per unit volume of water. Advantages of enumeration are 1) organisms to be counted must be looked at, thus bringing to the attention of the investigator unusual changes in appearance, 2) species represented by few individuals can be detected, and 3) plankters are distinguished from debris (Lund and Talling 1957). In addition to revealing the total abundance of phytoplankters, the count data are useful in deriving biovolume and diversity indices.

Because cell-size differs greatly among species of algae, counts do not always convey a true picture as to the bulk importance of phytoplankters. Counting can be a time-intensive process; however, subsampling and attention to the abundant species can reduce the time commitment. Reliable identification of algal species is a matter for highly trained workers.

Abundance data are suitable for between-station comparisons at a moment in time, i.e., discharge areas vs. a "control" site removed from discharge influence. Because of the great natural variation in numbers in phytoplankton populations, it is extremely difficult to establish statistically significant changes in between-year or before-and-after comparisons.

Biomass. Biomass of phytoplankton is usually expressed as weight or volume of plankters or in terms of a cellular constituent such as carbon, nitrogen, chlorophyll, or ATP (adenosine triphosphate).

Although a gravimetric approach to determining phytoplankton biomass seems straightforward enough, complications arise because collections of phytoplankton from natural waters are always contaminated by zooplankters and bits of allochthonous and authochthonous detritus. For some purposes it may be sufficient to determine dry or ash weight of plankton-net catches; however, the investigator must remember that his net takes inorganic particles and organic debris as well as phyto- and zooplankters. In this instance, it is correct to refer to the catch as seston.

In the present state-of-the-art, it is not possible to separate phytoplankters from other particles in plankton samples, except visually. Enumeration, which requires identification and counting, may be used in estimations of biomass expressed as volume or weight.

Shapes of phytoplankton cells are often approximated by geometric figures whose volumes are calculable by formulae. A number of cells are measured and mean values obtained which are inserted into appropriate formulae; number of cells multiplied by average cell volume is an estimate of biovolume of phytoplankters. An assumption about density permits estimation of weight of phytoplankton.

Chlorophyll is widely measured as an index of standing crop of phytoplankton. Chlorophyll and other photosynthetic pigments are, of course, important in the photosynthetic process and therefore closely associated with primary production. A major advantage to chlorophyll determinations is that several samples can be processed quickly with relatively modest equipment. Corrections can be made for chlorophyll degradation products, phaeophytin, thereby measuring only live chlorophyll. Chlorophyll may be measured by autofluorescence (Wood 1962). The major disadvantage to chlorophyll as a parameter of biomass is that results are difficult to understand, and the data are not easily manipulated, in spite of factors that may be used to convert chlorophyll to carbon.

Nitrogen, carbon, and silicon content have been used as estimators of standing crop of phytoplankton. Strickland (1960) indicates that of these, estimation of carbon content is the most satisfactory. However, zooplankton and detritus present will influence the determination as they do in gravimetric measurements. The advantage lies in the close relationship of carbon to organic production. The laboratory procedures for either wet or dry oxidation are not simple, and instrumentation requirements for dry oxidation are considerable.

ATP is believed to measure only living phytoplankton cells (Vollenweider 1974) because of its rapid loss after death. The advantage of measuring only primary producers in collections contaminated with detritus and zooplankters is clear. ATP determinations suffer from the same disadvantages as chlorophyll analyses: Results are difficult to interpret and are not readily manipulated in data analysis.

Diversity. Diversity is a measure of complexity in the composition of communities. It is useful for comparing communities and as an index of environmental conditions. Since diversity is computed from both the number of species in the community and the apportionment of individuals among species, identifications and counts are required. If counts are already available, diversity may be calculated with little trouble. The advantage is in having a dimensionless number which permits inter-community comparisons or observed species-numbers distribution with theoretical apportionment. Diversity may be calculated from several formulae; Pielou (1975) discusses the theoretical bases for them. The principal disadvantage lies in interpretation of index values.

Indicator Species. Indicator species and associations of phytoplankters are sometimes useful in conveying information about aquatic habitats. The narrower the range of environmental conditions that a species can tolerate, the more information is revealed by its presence in a particular body of water. The use and value of indicator species are best worked out in relation to pollution of streams and lakes. Hynes (1960), Warren (1971) and Lowe (1974) discuss aspects and usefulness of indicator species and associations, particularly in regard to pollution.

One of the best-documented examples of a species signaling an important change in a lake ecosystem involves the blue-green alga Oscillatoria rubescens. The sudden appearance of O. rubescens in the summer plankton of several European lakes and in Lake Washington, U.S.A., has occurred shortly before these lakes reached severe and undesirable levels of eutrophication. In Lake Washington, subsequent reduction of nutrient levels following diversion of sewage effluent, caused the disappearance of O. rubescens from the plankton.

The advantage of being able to draw conclusions about environments from collections of phytoplankters is evident, especially if time and effort have gone into identifying and counting them. Disadvantages are that inferences require accurate identification, specific requirements are known for relatively few species, and freshwater species generally can tolerate, if not thrive in, broad spectra of environmental conditions.

Productivity. Productivity, or rates of production, estimates focus on the dynamic processes that form new primary organic material. The light- and dark-bottle technique is widely used. This technique measures oxygen evolution from, or radioactive carbon uptake in, photosynthesis. In the former, the content of dissolved oxygen in samples of phytoplankton is determined. Then the samples are sealed in clear and completely opaque bottles. After an incubation period of 4 to 24 hours, either in controlled laboratory conditions or in the waters from which the samples were drawn, oxygen concentrations are again measured. The opaque bottles are used to estimate oxygen required for respiration. Excess of oxygen in the clear bottles over the opaque is an estimation of net photosynthesis, i.e., gross production minus metabolic costs of producing it. Respiration of both zooplankters and bacteria influences oxygen utilization, so community relations are measured in mixed samples. Because oxygen concentration changes must exceed minimum detectable limits, only waters where phytoplankers are fairly dense will produce satisfactory results by this method. In some instances it is possible to view a lake or pond or a section of a stream as a large light/dark-bottle experiment and use changes in oxygen as estimators of *in situ* community metabolism (Odum and Hoskin 1958). Ratios of gross production to respiration permit conclusions about overall trends in community succession (Odum 1971). Light/dark-bottle determinations of dissolved oxygen may be performed with a minimum of equipment.

Because the carbon 14 method is much more sensitive than the oxygen technique, it can be used in waters that are poor in phytoplankters. Light and dark bottles are used as described for oxygen experiments. Very small amounts of radioactive carbon, as sodium bicarbonate, are added, and after a given time, the amount of C^{14} assimilated is measured. The ratio of marked carbon taken up to total inorganic carbon present is an estimate of total carbon fixed by photosynthesis. The advantage of this technique is that it measures the dynamic photosynthetic process, thereby quantifying rates at which new organic matter is synthesized. Zooplankters included in mixed samples do not directly take up the radio tracer, although they may eat phytoplankters that have. Bacteria do in some instances take up the tracer. The most serious disadvantage is the requirement for special equipment and highly trained personnel.

Summary. The usefulness of phytoplankton data is confined to baseline studies in standing waters. Quantitative data are useful in assessing community food-webs, and qualitative data often permit drawing conclusions about overall environmental conditions and trends. Natural year-to-year variations in standing crops severely limit the usefulness of quantitative data in before-and-after comparisons. Generally, the phytoplankton community is of no interest in the majority of running water systems. It thus can be safely ignored in most baseline studies.

As a minimum, low-level baseline survey of a standing-water system should include information on phytoplankton species composition, relative abundance, diversity, and biomass.

A high-level baseline effort should include, in addition to low-level items, information on chlorophyll and estimates of productivity based on oxygen and carbon 14 uptake. It is unlikely that population studies on individual species would be part of any baseline study. Irrespective of level of effort, the investigator should attempt to determine factors that appear to limit phytoplankton production; even qualitative assessment is useful.

6.5.4 Periphyton

Periphyton is a collective term referring to algae that grow attached to substrata in standing or flowing waters. Substrata may be of inorganic materials (rocks, sand, mud), live organic matter (cattail stems), or dead organic matter (logs). The periphytic algae are primary producers. In standing waters, periphyton is found along shore and lakeward to the limit of light penetration effective for photosynthesis. In flowing water, periphyton is confined to stable substrata within favorable light intensity.

Because species composition and biomass vary seasonally, periphyton presents the same problems for before-and-after studies that phytoplankton does.

Natural substrata that support periphytic growth are usually rough and very difficult to sample quantitatively. This has led to the use of artificial substrata of plastic, glass, or other materials. Sladeckova (1962) reviews techniques and aspects of sampling periphyton. Table 6-13 lists attributes and parameters of periphyton.

Abundance. The number of cells per unit area of natural or artificial substratum is a widely used parameter to describe periphyton. Abundance data for periphyton may be measured in much the same way as for phytoplankton. Artificial substrata are particularly convenient because the relatively smooth surfaces facilitate complete removal of periphyton from a precisely known area.

Diversity. If identifications and counts of periphytic algae have been made, diversity is readily calculable from formulae discussed by Pielou (1975).

Indicator Species. The nature of the substratum markedly influences which periphytic algae will grow on it and the specific requirements of most species are not well known. Hutchinson (1975) reviews extensive investigations of diatom communities on natural substrata. Patrick (1957, 1964, and 1968) studied diatoms as indicators of organic pollution. Patrick (1977) has summarized both the current understanding of physical and chemical factors that are most significant to the occurrence of diatom species and the literature on structure of diatom communities in relation to environmental conditions.

Productivity. Periphytic primary production may be investigated by either the oxygen-production or carbon-14-uptake techniques. The advantages and limitations of each were discussed earlier. Periphyton from flowing water presents special problems because flow conditions are difficult to simulate in the laboratory, and measurements made on periphyton removed from natural flow are unreliable in their ability to reflect natural metabolism.

Summary. The periphyton needs to be considered in baseline studies because of its importance as a primary-production source, particularly in many streams. Because periphyton grows on fixed surfaces, it is the recipient of whatever the currents bring to it; thus periphytic growth, both in species and amount, is an integrator of environmental conditions. Although natural variation between years makes comparisons over time difficult to interpret, changes in species or relative proportions of individuals among species may be an early indicator of a shift in environmental conditions.

Table 6-13. Attributes, parameters, and references to methods for the periphyton component of aquatic systems. Numbers in method columns refer to works cited at foot of table. These works contain specific information as indicated.

Attribute	Parameter	Method	
		Field	Laboratory
Abundance	Numbers	1,2,3,4,5, 6,7	1,2,4,5
Biomass			
Gravimetric	Weight		1,2,4,5,6,7
Volume	Measure, Count		6
Cellular Content	Carbon, Nitrogen Chlorophyll, ATP Calories		1,2,4,5,6,7
Diversity	Identification, Count		
Indicator Species and Associations			
Productivity	Dissolved Oxygen,		1,4,7
	Carbon 14 Uptake		1

1. American Public Health Association 1971
2. Weber 1973
3. Lund and Talling 1957
4. Schwoerbel 1970
5. Vollenweider 1974
6. Welch 1948
7. Sladeckova 1962

Periphyton should surely be included in high-level baseline studies of running water, with the following types of data taken as the minimum: species composition, relative abundance, diversity, and biomass. Periphyton can safely be omitted from low-level efforts.

6.5.5 Macrophytes

The macrophytes are all aquatic plants of macroscopic size; most are angiosperms, although certain green algae (Characeae) and some Bryophyta are locally important. Macrophytes are divisible into three groups, based on growth habit: 1) submerged - plants that are rooted in the substratum and which usually grow beneath the water, although floating leaves or stems that extend above the surface may be present, 2) emersed - plants that are rooted in shallow water and possess floating leaves or emergent stems, and 3) floating - plants that do not root in the substratum, but which float freely on the water.

Rooted macrophytes grow around the margins of standing water where substratum and other conditions are favorable; the lakeward limit of submerged growth usually corresponds closely to depth of penetration of light effective for photosynthesis. In shallow ponds, macrophyte growth may extend over the entire substratum.

Macrophytic growth along streams depends on current, substratum, and other variables.

Because they are primary producers, macrophytes are frequently important components of the systems in which they occur. While most macrophytes are not grazed directly by aquatic organisms, they contribute to the organic detritus pool. Macrophytes also provide food for waterfowl and shelter for small fish. Table 6-14 lists attributes and parameters for the macrophyte component.

Abundance. The numbers of plants per unit area is attainable, although biomass is more frequently measured.

Biomass. Weight, either fresh, dry, ash, or loss on ignition, per unit area is the most frequently used expression of biomass. Since most macrophytes are relatively long lived, harvest sampling at the end of the growing season is an estimation of net production for the year. Macrophyte stands are often readily identifiable from aerial photography, particularly from false infrared photography. Biomass can be estimated accurately when such mapping is combined with surface sampling.

Much of the total biomass of submerged and emersed macrophytes is contained in underground parts. Thus biomass figures should state whether total biomass or aboveground biomass was measured.

Cellular contents of macrophytes may be measured by the same techniques that are useful for determining cellular constituents of phytoplanktic and periphytic algae.

Diversity. Although diversity can be calculated by methods already cited, it is not done very often.

Table 6-14. Attributes, parameters, and references to methods for the macrophyte component of aquatic systems. Numbers in method columns refer to works cited at foot of table. These works contain specific information as indicated.

Attribute	Parameter	Method		
		Field	Laboratory	Data Analysis
Abundance	Numbers	1,2,3,4,6		
Biomass				
Gravimetric	Weight	7	2,3,4,5	
Cellular Content	Carbon, Nitrogen, Protein, Carbohydrate, Crude Fiber, Chlorophyll		3,4	
Energy	Calories			
Diversity	Identification, Count		4	
Productivity	Carbon 14 Uptake		2,6	5,6

1. American Public Health Associations 1971
2. Weber 1973
3. Vollenweider 1974
4. Wood 1975
5. Westlake 1965
6. Wetzel 1965.
7. Owens et al. 1967

Productivity. Carbon 14 uptake can be used to measure rates of production of macrophytes; however, it is rarely done in baseline studies.

Summary. Macrophytes occur irregularly in most western areas where energy developments are likely to take place. Since macrophytes are of considerable importance where they do occur, they should be included in baseline studies.

6.5.6 Zooplankton

Zooplankton, the animal portion of plankton, comprises microscopic and small (up to 5 mm) macroscopic organisms. The rotifers, cladocerans, and copepods constitute most of the numbers and biomass of the zooplankton, although protozoans may be numerous on occasion and other groups are sparsely represented at times. Broadly, two general types of feeding mechanisms are exhibited by zooplankters: filtering and seizing. Filter feeders strain small particles from the surrounding water by several mechanisms. Because small cells of phytoplankton may constitute much of the material being filtered, filter feeders are usually considered to be herbivores. Actually, bacteria, bits of detritus, very small protozoans, and other animals may, at times, be filtered and ingested incidentally. Seizers, which grasp and ingest food as individual items, are commonly regarded as carnivores. Body size is not a good criterion of feeding habits.

Zooplankters are important constituents in most standing-water biotopes because they are intermediate links in the food chains and webs between primary production and detritus and the larger animals that are of particular interest to man. Zooplankters may occur in slowly flowing rivers in reproducing populations. Although they may be collected in moderately swift rivers, they do not reproduce and maintain populations in the direct current.

In north temperate lakes, reservoirs, and ponds, zooplankters exhibit seasonal variability in standing crops and in species presence. Small zooplankters such as rotifers have individual life spans that are measured in days; cladocerans and most species of copepods have lives measured in weeks, although some of the latter may live for months. Table 6-15 lists attributes and parameters for the zooplankton component.

Abundance. By far the most common expression of standing crop of zooplankton is number per unit of volume of water.

Biomass. Gravimetric determination either as wet or dry weight per unit of volume is the most frequent expression. Sometimes weight per unit of lake surface is a useful way to express standing crop. Large zooplankters can be separated from most phytoplankters in mixed samples by using coarse nets. There is no way of separating small zooplankters from phytoplankton and detritus in mixed samples except visually. Chemical composition, usually as either carbon or nitrogen, is possible but is not ordinarily done in baseline studies. Energy flow investigations require expression of crop in calories, but again, this is not normally done in baseline studies.

Diversity. Copepods, which often make up a very large fraction of the zooplankton biomass, possess complex life cycles in which 10 or 11 instars occur between egg and adult stages. Unfortunately, immatures are not readily

Table 6-15. Attributes, parameters, and references to methods for the zooplankton component of aquatic systems. Numbers in method columns refer to works cited at foot of table. These works contain specific information as indicated.

Attributes	Parameter	Method	
		Field	Laboratory
Abundance	Number	1,2,4,5,6,7	1,2,4,6,7
Biomass			
Gravimetric	Weight		2,7,9
Volume	Measure, Count	7 6	
Chemical Composition	Carbon, Nitrogen	9	
Calorimetry	Calories	5,7,9	
Diversity	Identification, Count	8	
Indicator Species and Associations	Identification	1,3	
Productivity	Oxygen Utilization	5,7,9	

1. Environmental Protection Agency 1975
2. Weber 1973
3. Hutchinson 1967
4. Schwoerbel 1970
5. Southwood 1966
6. Welch 1948
7. Edmondson and Winberg 1971
8. Edmondson 1959
9. Winberg 1971.

identifiable to the species level, and they are much more abundant than adults during much of the year. Perhaps this inability to make specific identifications of large portions of populations has discouraged the use of diversity indices for zooplankton populations.

Indicator Species. The use of zooplankters as indicator species has lagged behind the use of algal species. Most attempts to use zooplankters as indicators have been directed toward using them as pollution indicators, as described by Brooks (1969), Wilkens (1972), and Gannon and Stemberger (1975). Hutchinson (1967) reviewed the occurrence of zooplankters in relation to environmental conditions.

Productivity. Secondary production involves processes of consumption of food and its transformation and utilization by animals. Edmondson and Winberg (1971) point out that knowledge of these processes is basic to understanding how natural communities are organized and how material and energy flow through them. These authors indicate that secondary productivity may be approached via population dynamics and through physiological studies. Baseline studies sometimes contain enough information to draw inferences about rates of secondary production through changes in standing crop, but rarely are these data sufficient to elucidate rates of population dynamics (i.e., rates of reproduction or mortality) and almost never are physiological processes (i.e., rates of feeding, respiration, excretion, etc.) considered.

Summary. Data on zooplankton should be included in baseline studies of standing bodies of water because of their importance in food webs. Because standing crops of zooplankton vary from year to year in response to biological factors and variables in the physical environment, changes in crop after a particular development has taken place are difficult to interpret as results of the development.

6.5.7 Macroinvertebrates

Macroinvertebrates refers collectively to all the invertebrate animals that live on or in the substrata of standing-and-running water biotopes. In general, forms large enough to be retained by screens having approximately .5-mm mesh are grouped as macroinvertebrates. The nature of the substratum and other characteristics greatly influence the kinds of animals found in the macroinvertebrate fauna of a given body of water.

Insects, mollusks, annelids, and crustaceans are the major macroinvertebrates. Because the substratum of most streams and rivers is not homogeneous, the macroinvertebrate fauna tends to occur in mosaic patterns. This complicates adequate sampling. In an effort to standardize sampling, or at least neutralize effects of substratum variability, artificial samplers of many styles have come into use.

Macroinvertebrates are an important and conspicous element in all freshwater communities, particularly in running water. Carnivores, herbivores, detritivores, and omnivores are represented. Feeding mechanisms include seizing, scraping, filtering, and sucking, either simple ingestion of substratum or tissues of animals or plants. Macroinvertebrates are immensely important in most aquatic food webs as food for fishes.

Macroinvertebrates dislodged from the substratum by flooding drift passively. However, drifting is part of the life cycle of many species and occurs in response to physiological or external stimuli that are much more subtle than floods. Thus, carefully planned baseline studies should include sampling of macroinvertebrate drift.

Most macroinvertebrates have life cycles that approach, if not exceed, one year. Nearly all are of restricted mobility. Because of length of life and low mobility, macroinvertebrates have been used as indicators of environmental conditions and as possible accumulators of sublethal amounts of pollutants.

Table 6-16 lists attributes and parameters for the macroinvertebrate component.

Abundance. The most common measurement of macroinvertebrates is number per unit of area. Abundances, however, are difficult to compare because of the great disparity in size among individuals of different species or individuals of different ages within one species.

Biomass. Biomass expressed as weight per unit of area is a widely used and understood expression. Less commonly, biomass is given in terms of chemical composition, such as carbon or nitrogen content. Caloric content is a valuable parameter in energy-flow studies, but is little used in baseline work.

Diversity. Much work has been done on computing diversity indices for macroinvertebrate communities. In general, high values are associated with diverse communities living in sites that are not stressed by pollutants or other factors. Such communities tend to be made up of many species that are rather evenly represented by numbers of individuals. With identification and count data available, indices can be computed readily. Since an index is a dimensionless number, interpretation of count data may not be straightforward.

Indicator Species. The accurate identification of species of macroinvertebrates is a matter for the expert, just as it is for algae and zooplankton. Presently some immature stages cannot be positively identified to the specific level without rearing them to adults. The distribution of macroinvertebrates has been widely studied in regard to substrata, pollutants, and other environmental variables (Hynes 1960 and 1970). Cummins (1974) points out that some of the problems inherent in species recognition as a means of environmental assessment can be alleviated by recognizing functional groups of organisms. Immature insects of many streams can be classed in four categories based on feeding mechanisms. Feeding mechanisms are functionally related to the basic trophic levels prevailing in the various sections of streams, i.e., sections where within-stream autotrophic production predominates vs. sections where allochthonous input of organic material predominates. Thus, possibly a change in proportions of basic feeding types may signal an ecosystem change before it can be detected quantitatively by using the biomass of the entire macroinvertebrate community.

Gaufin (1973) emphasizes that relative abundance of species is much more useful in evaluating environmental conditions in streams than is knowledge of presence or absence.

Table 6-16. Attributes, parameters, and references to methods for the macroinvertebrate component of aquatic systems. Numbers in method columns refer to works cited at foot of table. These works contain specific information as indicated.

Attribute	Parameter	Method	
		Field	Laboratory
Abundance	Number	1,2,3,4,5	1,2,5,6
Biomass			
Gravimetric	Weight		2,5,6,7
Volume	Count, Measure	5,6	
Chemical Composition	Carbon, Nitrogen	6,7	
Calorimetry	Calories	4,6,7	
Diversity	Count, Identify	2	
Indicator Species and Associations	Identify	2	
Productivity			4,6,7

1. American Public Health Association 1971
2. Weber 1973
3. Schwoerbel 1970
4. Southwood 1966
5. Welch 1948
6. Edmondson and Winberg 1971
7. Winberg 1971

Hart (Hart and Fuller 1974) wrote in the preface of a recent text summarizing information on protozoans, sponges, flatworms, leeches, aquatic earthworms, bryozoans, crayfish, mollusks, and insects, "Ideas about pollution indicator species . . . range from the simplistic (yet tantalizing) quest for an all-purpose aquatic 'canary' that will warn of pollution to complex mathematical models of community interrelationships . . . But there is no aquatic canary. Neither is there any one index or model that can be depended upon to describe a community completely. Rather, a balance of many techniques -- including species compositions, population sizes, and the physical-chemical environments to which they are exposed -- must be employed."

Productivity. Successive measurements of standing crop are a rough index to rate of net production. In addition to sampling errors, such an index is markedly influenced by the life cycles of organisms composing the crop. For example, eggs and small instars of insects pass through screens normally used and are lost. Because macroinvertebrate crops are influenced by environmental factors of flow, temperature, and other physical factors that vary from year to year, across-year variations in crop are very difficult to evaluate. Winberg (1971) and Edmondson and Winberg (1971) discuss problems of estimating secondary production in monocyclic and polycyclic species from both physiological parameters and static parameters, such as population numbers, individual growth, and food consumption.

Summary. Baseline studies should contain data about kinds and amounts of macroinvertebrates that occur in flowing and standing freshwater biotopes. Assemblages of species may reveal important clues to environmental conditions.

A high-level baseline study of a running-water system should certainly pay close attention to composition, relative abundance of feeding types, diversity, biomass, and spatial and seasonal distribution of the macroinvertebrate community.

A low-level baseline investigation of a standing water system should contain at least preliminary information about the macroinvertebrate communities living in the major habitats offered by the system. A high-level study of a standing water system should include thorough estimates of the macroinvertebrates, particularly to include seasonal changes in biomass. Quantitative estimates of biomass are prerequisite to employing system indices.

Because the composition of the substratum affects the kinds and quantities of macroinvertebrates, brief examinations of the physical habitat may indicate factors that limit production of benthos; e.g., streams with bottoms of loose, unstable sand do not afford suitable habitat for macroinvertebrates. Conversely, stream bottoms of stable gravel and mixed sizes of rubble are expected to support a diversified assemblage of macroinvertebrates. If cursory examination suggests that macroinvertebrates are absent, the biologist should be alerted that an unfavorable factor may be operating.

6.5.8 Fish

Fishes represent the elite of aquatic communities, not only because they are the terminal points of food chains, but because of size and relative conspicuousness. In freshwater environments, fish have recreational, commercial, and aesthetic value. In western energy-development areas few, if any, invertebrates are recreationally or commercially important, and none has sufficient aesthetic appeal to be a candidate for endangered or threatened status.

Unlike freshwater invertebrates, fish populations are composed of relatively long-lived individuals that persist through seasonal and other changes in their environments. Because of long life-spans, fish may act as bioaccumulators of certain metals or organic compounds. Moreover, many species carry a history of their environment as a place for individual growth in scales, otoliths, or other body parts. Long-term changes in relative abundance of species, growth-rates, or reproductive success may indicate changes in the population's environment. Table 6-17 lists attributes and parameters for the fish component.

Abundance. Except in very unusual circumstances, it is virtually impossible to obtain a meaningful estimate of absolute abundance of a fish population. Because of differing habits and sizes among different species, no single technique will work for all. In fact, several methods may be needed to capture all sizes of a single species. Thus abundance is best expressed as numbers caught per unit of fishing effort, i.e., numbers per trap night or meters of stream electrofished.

Biomass. Since fish are captured by the same techniques for biomass determination as for enumeration, biomass estimates are subject to the same restrictions. Sometimes long-term data on biomass are available from commercial or sport fishery records. These data may be useful in detecting trends, but they are biased in a number of ways, including gear selectivity, market price and fishing pressure, and biological factors.

Diversity. Diversity indices are computable by any of the formulas available, but are not often figured. Hocutt, et al. (1974) compared diversity with the Jaccard similarity coefficient and found the latter to be more useful for comparing fish populations caught at different stations or at different times. The number of species of fishes is so much smaller than the numbers of species of algae or invertebrates that the possible range of diversity index values is sharply limited. Relative abundance of species is probably more meaningful than diversity in comparing fish communities and may provide insight into general environmental conditions.

Indicator Species. In general, fish associations are more apt to be indicative of warm or cold waters rather than of specific conditions. The mobility of fishes reduces their usefulness as indicators of environmental conditions.

Sometimes it is possible to combine attributes into indices that reveal insight into the well-being of a system as a whole. For example, Gammon (1976) investigated fish populations in 340 km of the Wabash River in Indiana. He found that a composite Index of Well-Being (IWB) could be derived by combining four attributes for the fish community: number of individuals/km of stream electrofished, weight of fish caught/km, Shannon index of diversity based on density of individuals, and Shannon index of diversity based on relative biomass.

Table 6-17. Attributes, parameters, and references to methods for the fish component of aquatic systems. Numbers in method columns refer to works cited at foot of table. These works contain specific information as indicated.

Attribute	Parameter	Method		
		Field	Laboratory	Data Analysis
Abundance	Number	1,2,3,4,7		
Biomass				
Gravimetric	Weight		3,4	3,7
Diversity	Identification, Count			
Indicator Species and Associations	Identification	3	3	6,9
Endangered, Threatened Species	Identification			
Productivity				4,5,7,8
Population Statistics				
Length, Weight, Age Distributions			2,3,4,8	2,3,4,8
Growth Rate	Length, Weight, Age		2,3,4	3,4,7,8
Condition	Length, Weight		2,3,7,8	7,8
Sex Ratio			4,7	
Fecundity			4,7,8	8

1. American Public Health Association 1971
2. Weber 1973
3. Lagler 1956
4. Ricker (ed.) 1968
5. Winberg 1971
6. Hynes 1970
7. Bennett 1971
8. Weatherley 1972
9. Gannon 1976

The IWB had a lower coefficient of variability than did any individual attribute. Plotting the IWB against river-mile-identified locations where factors markedly influenced the well-being of the fish community in regard to numbers or kinds of fish and their biomass. Possible causative factors could be identified in most instances; however, a few could not. Interestingly, some factors, such as discharge of heated effluents from electric generating stations, which might have been expected to influence the IWB, did not.

Endangered and Threatened Species. Some species have merited special attention by being placed on federal or state lists as endangered or threatened. They must be considered on a site-by-site basis.

Productivity. Productivity may be estimated indirectly from changes in biomass over time. Refined estimates include provision for growth and reproduction. Rarely do baseline data permit meaningful estimates of productivity, i.e., rate of production. Because production is a dynamic process responsive to several variables, it may not be "a satisfactory measure of the importance of fish as a trophic group in the aquatic community" (Chapman 1968).

Population Statistics. Since fish are relatively long-lived, it is possible to derive information about the population from one-time sampling efforts. Frequencies of length, weight, or age provide insight into histories of growth of individuals and reproductive successes of the population. Graphs of length or weight vs. age indicate how rapidly individuals are growing and mean size at a given age.

Length and weight measurements can be used to calculate condition factor. Condition factor is sometimes regarded as an indication of plumpness or well-being. It is influenced by several variables, as discussed in the references or Table 6-17.

Fecundity is the number of ripening eggs per female prior to the next spawning period (Bagenal 1968). Fecundity is influenced by several factors not the least of which is the weight or age of the female fish.

Summary. Data on fish populations should be included in baseline studies wherever energy development impinges upon waters supporting fishes. Fishes are at or near the apex of most aquatic food webs, and their nutritional well-being depends on that of the lower levels. Thus, a diverse, healthy population of fishes, well-balanced in age distribution, is prima facie evidence of an environment that meets the population's food, shelter, and reproductive demands.

Fishes are notoriously difficult to sample quantitatively in an unbiased manner, and estimates of absolute abundance are hard to come by. However, fishes are long-lived, and they often carry in their bodies evidence about growth histories of individuals and reproductive success of populations. Moreover, fish may be accumulators of pesticides, heavy metals, or other environmental pollutants.

6.6 ABIOTIC FACTORS

Abiotic considerations in ecological baseline studies include air quality, water quality, edaphic factors, and hydrological factors. Water quality is discussed in Section 6.5.2 under Aquatic Systems. Air quality, soils, and hydrology are discussed in the following sections.

6.6.1 Air Quality

6.6.1.1 Definition and Purpose. The atmosphere serves as an important transport medium for introducing materials into an ecosystem. The gaseous, solid, and liquid components of the atmosphere directly and indirectly affect the structure and function of an ecosystem. Characterizing meteorological parameters provides insight into their effects on plant and animal communities. Additional parameters must be characterized when we attempt to determine how atmospheric pollutants may affect the system. These additional parameters, which must be evaluated in baseline studies, include the gaseous pollutants of potential concern, atmospheric particulate loading, and rainfall chemistry.

6.6.1.2 Methods. Air quality and meteorological data must be collected in such a manner that they can be related to biological questions of concern. This requires good communications between biologists and meteorologists to insure that the proper parameters are monitored and that the data are collected and processed in a manner that allows their biological significance to be evaluated. Table 6-18 lists attributes and parameters commonly measured and summarizes methods for measuring them.

Collecting meaningful data on gaseous air quality usually requires continuous monitoring. The data that these monitors produce can be used to identify diurnal, seasonal, and annual fluctuations, and can also yield information on peak concentrations that occur during hourly averaging periods. Wet-chemistry and plate-monitoring techniques that attempt to integrate the atmospheric loading of a selected pollutant over time periods ranging from an hour to a month are frequently unsatisfactory. Problems associated with handling the chemicals and conducting the required analyses, as well as the inability to apply the resulting data to answer specific environmental questions, often critically limit the utility of these monitoring techniques.

The use of pollutant-specific monitors that operate on a continuous basis in conjunction with strip-chart or magnetic-tape recorders are usually the most satisfactory type of monitoring facility. When coupled with a systematic program of instrument calibration, this type of monitoring system provides accurate data that can provide the maximum amount of biologically applicable information. The pollutant-specific quality of the monitors is an important factor. It insures that the data are for a specific gaseous entity and that the values do not represent interfering gases.

Dispersion models are commonly used to evaluate impacts on air quality from a proposed emission source. Models can be applied to gaseous and particulate emissions. The accuracy of the predictions that these models generate must be viewed with some caution, however. Terrain irregularities, emission fluctuations, and meteorological variations can collectively or individually produce ground-level concentrations that differ significantly from the predictions. Many dispersion models predict short-term and long-term peaks of

Table 6-18. Standard components, attributes, parameters, and methods for evaluating air quality

Attribute	Parameter	Method	Sampling Program Design	Gases	Particulates	Liquids[a]
Concentration	Milligrams/Cubic Meter Parts/Million	EPA Standard Method or Approved Equivalent	6[b]	1,3,4 7		
Loading	Milligrams/Cubic Meter	High Volume Sampler	6		1,3,4 5,7	
Sizing	Milligrams/Size Class	Cascade Impactor	6			
Elemental Composition	Parts/Million Percent	Various Analytical Methods		5,7		
Acidity	pH Molarity	pH Meter or Titration				2
Chemical Composition		Various Analytical Methods				2

(a) Techniques applicable to precipitation chemistry are in evaluation stages.

(b) References for methods commonly used in the collection and analyses of data on air quality for baseline studies.

1. Air quality monitoring procedures established by state agencies
2. Dochinger and Seliga 1976
3. Instrument manuals published by manufacturer
4. Intersociety Committee 1977
5. Mercer 1973
6. Nell and Miller 1977
7. Sittig 1974

annual ground-level-concentration. If meteorological patterns differ significantly throughout the seasons, these annual dispersion predictions may differ significantly from the actual seasonal patterns of dispersion. Since vegetation is most sensitive to atmospheric pollutants during the summer growing season, modeling the dispersion for this period is important if seasonal meteorological variations occur.

Atmospheric particulate loadings are generally monitored with a collector that pulls a known volume of air through a filter in a specified period of time. The loading in the atmosphere is then calculated by measuring the weight of material on the filter and knowing the volume of air sampled and the sampling time. The calculated value represents the mean weight of particulates in the atmosphere over the sampling period. Since a relatively few large particles can greatly influence this mean value, and since the biological importance of particles varies with their size, many systems separate particles by size as they are collected. The data from this sampling procedure describe the important size distribution of particulate loading.

In addition to particle loading and size distribution, the chemical nature of the particles must also be analyzed. Determining the organic and inorganic fractions, the natural and anthropogenic components, the elemental composition of the components, and the potential biological availability of these elements are critical to understanding the biological significance of the atmosphere's particulates.

The chemistry of rainfall entering an ecosystem may significantly influence plant and animal communities of the system. Precipitation serves as a major source of nutrients in an ecosystem. However, the detailed chemistry of rain and its temporal and spatial variation are not well understood at this time. It is believed that in many areas of the world, rain chemistry is being significantly influenced by atmospheric emissions. The primary effect on rain chemistry is considered to be a decrease in the pH, or an increase in acidity, of rainfall. Emissions of acid-forming gases, such as sulfur dioxide and nitrogen oxides, are believed to be reponsible for this change. In certain baseline studies, defining the chemical nature of rain may be an important requirement particularly if the release of acid-forming gases by the proposed facility is anticipated.

Techniques for collecting and analyzing rainfall are being defined and standardized. The method of collection, period of storage, and method of storage can all affect the chemistry of the rainfall sample. Analytical procedures and key paramters to be evaluated are still being established. Although currently many unknowns are associated with changes in rainwater chemistry and their biological effects, increased attention is being directed toward the problem.

6.6.1.3 Interpretation of Data. Air quality data from both the monitoring program and the dispersion predictions can provide a considerable information about the atmosphere's influence on the ecosystem being evaluated. The data must be processed to produce statistics that are biologically meaningful. If we are aware of potential errors in predicted values, the biological significance of dispersion-model output can also be evaluated.

The concentration-averaging periods should be those that allow the stresses to be associated with possible impacts. Annual averages generally provide little information regarding periods of stress. Averages from periods ranging from hours to weeks are generally more informative. Attention should also be directed toward possible seasonal variations in monitored pollutant concentrations and how these variations relate to the growing season. Such variations may indicate seasonal changes in meteorological patterns and a corresponding need to generate seasonal predictions of emission dispersion. If continuous monitors are used to measure gaseous pollutants, a variety of concentration-averaging periods may be employed. With other instruments, or with particulate and precipitation monitoring equipment, the averaging periods may be fixed or may be too long to provide the desired information. The averaging periods available in the dispersion model may also be quite limited.

The monitored and predicted pollutant concentrations may be compared to the Federal air quality standards to determine whether violations have occurred or will occur. Gaseous pollutant concentrations can be compared to the published injury thresholds for the species found in the area. However, substantial differences in injury thresholds can occur between plants exposed in a laboratory and those exposed in the field. These differences are generally influenced by the environmental conditions under which the plants grew and were exposed. Thus, the general environmental conditions in the study are and their effects on plant sensitivity must be considered when evaluating the potential phytotoxicity of a particular gaseous air pollutant.

The biological effects of the monitored and predicted particulate loading must be evaluated in conjunction with several additional parameters: the particulates' elemental composition, their biological availability, and the actual deposition rate of the materials into the system. The elemental composition of the particulates will provide insight into the presence of potentially toxic concentrations of various elements. If these elements are highly soluble or otherwise biologically available, they may be readily taken up by plant roots to produce phytotoxic concentrations in the plant tissues.

The deposition rate of the particulate load is another important consideration. The physical characteristics of the various particulate fractions will cause them to precipitate out of the atmosphere at different rates and will affect their ability to cling to foliar surfaces or to penetrate leaf stomata. Thus, the actual deposition rate of particulates into the ecosystem provides specific information on potential biological effects that may not be apparent from the atmospheric loading. Biological availability and deposition rate parameters of particulates are not commonly evaluated, although they can provide insight into potential effects that particulates may have on an ecosystem.

Rainfall chemistry is receiving considerable attention in the United States. Much of our present knowledge regarding the effects of altered rainfall chemistry on ecosystem components has come from Europe and the Scandinavian countries. These studies relate acid precipitation effects to both terrestrial and aquatic ecosystems. Because acid precipitation problems result from point and area sources of emissions, they are regional in scope. The influences of these emissions may occur far from their source, since these materials are commonly transported long distances before being deposited by rainfall.

As rainfall collection and analysis techniques improve, it will become increasingly important to examine rainfall chemistry and evaluate its influence on biological systems. The incremental effect on rainfall chemistry of a single point source is probably minimal. However, examining the chemistry of rainfall in a baseline study may help to explain an environmental perturbation that is subsequently observed and which may be incorrectly attributed to the emissions of the new source.

For example, a well designed baseline study for a coal-fired electrical generating plant should monitor gaseous, solid, and liquid components of the atmosphere, predict their increase as a result of plant operation, and evaluate their present and potential impacts on vegetation. Sulfur dioxide, oxides of nitrogen, and ozone should be monitored continuously at the site of the proposed facility. Particulates should be collected by fractions and analyzed to determine their physical and chemical properties. If acid precipitation is a concern, precipitation should be monitored according to the latest approved procedures. Standard meteorological parameters should also be monitored to provide information on pollutant transport and seasonal variations, and to help define potential vegetation sensitivity to the pollutants. The monitoring program should operate for at least one full year, although several years' data will more completely characterize the atmosphere's components.

Air quality data should be processed and analyzed with the objective of producing biologically relevant information. Direct particular attention toward averaging periods and seasonal variations. Compare pollutant concentration data with existing air-quality standards and threshold injury concentrations for plant species in the area.

In conjunction with the air-quality monitoring program, conduct a vegetation survey. The objectives of this survey are to evaluate the existing levels of vegetation injury in the study area, to determine which pollutants are producing injury, to catalog the species affected, and to determine the spatial extent of the affected area. Locate plots permanently in a systematic network throughout the study area, and examine them at least twice during the growing season. The evaluations of injury should produce a record of the species affected, the type of injury, a quantitative evaluation of severity, and the pollutant probably responsible. Record observations of other disease and insect stresses also. Analyze foliage samples from selected plants for concentrations of chemical elements. Evaluating foliar levels of sulfur and other selected elements, such as fluoride and heavy metals, can help define existing stresses on the vegetation and can serve as baselines for evaluating the incremental stresses that energy development might create. Evaluate any air-pollution injury observed in light of the pollutant concentrations that were monitored during the growing season.

Include in the dispersion model the monitored meteorological parameters and the monitored air-quality data. Engineering estimates of anticipated emissions are also required for the model. Obtain seasonal predictions of dispersion also, if possible, and predict dispersion for both the major gaseous emissions and particulates. An analysis of the size distribution, elemental composition, and biological activity of the particles being released from the stacks is also useful in predicting their potential environmental impacts.

Evaluate these patterns of pollutant dispersion with respect to pollutant-sensitive species in the area to examine the relationships between predicted concentrations, and air quality standards, and vegetation injury thresholds. An evaluation of these factors will help locate those areas having the highest probability of pollutant impacts to vegetation. These are the areas in which to conduct detailed and critical studies of impacts to plant growth or yield. Although the dispersion model can be a powerful tool for estimating potential pollutant impacts, significant deviations from the predicted pollutant concentrations and their geographical locations can occur.

6.6.1.4 Summary. An air quality program should meet two objectives: It should evaluate current atmospheric parameters, and it should predict how these parameters will change with development activities. The gaseous, soild, and liquid components in the atmosphere may be evaluated, although the overall scope of the monitoring program will be determined by the nature of the proposed development. Refinements that can be added to a program, such as monitoring additional pollutants, sizing particles, characterizing elements, and analyzing rainfall, add to the baseline information; but the value of these data must be weighed against both the additional cost and the utility of the data in evaluating potential impacts.

Care must be exercised in the application and interpretation of dispersion model output. The possibility of significant deviation from the predictions must always be considered. The effects of seasonal changes in meteorology on the predicted dispersions may be an important factor. If these changes are pronounced in the study area, seasonal dispersion predictions may be required.

In all cases, data should be processed to produce statistics that have biological applications. The data may have to be analyzed to provide seasonal information over short averaging periods. When pollutant concentrations are viewed in conjunction with the species present, species sensitivities to the pollutants, and the environmental parameters which affect these sensitivities, it is possible to evaluate the pollutants' potential for vegetation injury.

6.6.2 Soils

Soils form the growth medium for autotrophs, serve as a nutrient reservoir, and store water. Edaphic properties and climate are the primary factors controlling plant productivity, and thus indirectly controlling animal productivity. Soils absorb, bind, and break down toxic materials and can also pass them on to air, water, and living organisms. Knowledge of baseline characteristics of existing soils is also necessary for site restoration or reclamation.

6.6.2.1 Methods. Obtaining published soil-survey information is one of the most efficient methods of gathering soil data for use in baseline studies. The Soil Conservation Service is the federal agency whose primary responsibility is to map and evaluate the soil resources of the United States. Other federal agencies, such as the Bureau of Land Management and the Forest Service, as well as various state agencies, also conduct soil surveys on a more limited basis. Checking the data available from such organizations can prove fruitful in beginning a baseline study of the soil resource.

The resolution and accuracy of data available from soil surveys varies considerably. General soil maps that show the soil resource of an entire state based on a combination of limited field mapping and remote sensing are generally termed "fifth-order" surveys. These depict phases of subgroups, great groups, suborders, and orders. Due to the generality of data and the small mapping scale (1:250,000 to 1:1,000,000), this level of soil survey is not appropriate for definitive baseline studies or for reclamation planning.

Surveys applicable to environmental baseline studies and subsequent reclamation efforts are those of the first, second, or third order. These were prepared by the Soil Conservation Service and various other state and federal agencies. These levels identify spatial distribution and provide interpretive data that are useful for planning subsequent reclamation or mitigation efforts.

Whenever available and applicable, first-order surveys should be utilized. These surveys are based on a mapping scale of 1:12,000 with minimum size delineations (the smallest body of soils differentiated) of 1.5 acres. Because the maximum amount of mapping effort is expended at this level of survey, this order provides the most definitive information at the soil series (phase) level. Consociations and some complexes are the primary map units displayed at this level of resolution. Intensively utilized land, such as urban areas or irrigated farmland, are surveyed at this level.

The second-order survey also describes phases of soils series, but mapping is done at a somewhat broader scale. Mapping scales for this order range from 1:12,000 to 1:31,680, and minimum size delineations range from 1.5 to 10 acres. Relatively intense field mapping at this level is supplemented by interpretations of remotely sensed data. Consociations, associations, and complexes are the kinds of map units identified in the second-order soil survey. This is the most common level of survey utilized by the Soil Conservation Service.

Third-order soil surveys are the most general level of surveys that should be considered for baseline studies. These surveys identify soil associations, some consociations, and some complexes, with soil series and soil family phases as components. Mapping scales for this level of intensity are from 1:24,000 to 1:250,000, with minimum size inclusions ranging from 6 to 640 acres. Soils are mapped at this level using a combination of existing field maps, new field observations, and remote sensing interpretations. This level of survey is most common in mountainous areas, rough lands, or for areas that are not intensively utilized.

Interpretive data that can be utilized for baseline studies and reclamation planning is available in the form of "SCS Form-5" soil reports. These reports depict a variety of physical and chemical soil characteristics at the soil-series level. Information commonly available includes series name, temperature and moisture regime, drainage characteristics, parent material, soil depth and horizonation, texture, liquid limit, plasticity index, permeability, available water-holding capacity, pH, salinity, shrink-swell potential, corrosivity factors, erosion characteristics, flooding potential, soil-use criteria, productivity indices, and various suitability ratings. While not all of these characteristics have been developed for all soil series, consultation with soil scientists familiar with the area can serve to fill in many of the information gaps.

Although this type of information is often available from various government sources, in many cases soil surveys do not exist for areas where energy development is to occur. In such cases, or where published soil surveys do not contain suitable or adequate information in relation to the energy-development activity, it is necessary to conduct a soil survey and develop interpretations geared to specific study objectives. The following is an example of how on-site soil studies can be developed when published soil data are insufficient for project needs.

Field and laboratory techniques and data analysis will depend on study objectives. Table 6-19 contains a list of references for soil-study methods. Study objectives might include vegetation (natural or agricultural crops) and soils productivity relationships, wind and water soil-erosion hazards, potential for improvement through soil conservation and habitat improvement, capabilities for reclamation after disturbance, drought potential, salinity problems, drainage problems, and storage and transfer of toxic substances in soils. Biological changes that result from construction and operation of an energy-development activity can often be predicted by the study of soils. Soils can serve as indicators of potential stresses for biotic systems.

Soils programs must consider the number and complexity of soil series and associations, origin of soils, slope, aspect, relief, chemical properties, surface and subsurface hydrology, soil depth and texture, macroclimate, microclimate, natural biotic influences, and human influences. Sample locations and replications depend on heterogeneity on the study area, attributes to be studied, and desired confidence in the data. For site restoration or habitat manipulation it is generally necessary to analyze key physical characteristics and chemical constraints (e.g., pH and availability of macronutrients) for sufficient details to complete the programs. If an area is to be returned to its original, natural plant communities, detailed physical and chemical studies will be required, and laboratory or greenhouse studies of the key plant species and soils relationships may also be required.

In areas where past human activities have altered the productivity of the soils, such as by increasing salinities, herbicide concentrations, pesticide concentrations, and other toxic substances, the soil characteristics should be documented. This documentation will insure that adverse conditions are not unjustly attributed to the development at a later date. To design a program to measure and monitor toxic substances, the history of the area must be known. Potential areas for adverse impacts can be identified from dispersion data for stack emissions, cooling-tower drift, airborne flyash, and airborne particles. These potential areas may warrant study during the baseline period to enable quantification of impacts, design of mitigation procedures, and development of a historical reference for future monitoring programs.

The greatest problem in all soils studies is the variability of data associated with improper collection and insufficient number of samples. Generally, laboratory techniques are not a cause of significant variability in the data. Trace element and pesticide analyses are complex and require appropriate precautions to prevent sample contamination and to insure proper analytical techniques.

6.6.2.2 Interpretation of Data. Soils data must be presented in such a way that they will be useful in describing the abiotic characteristics of the

Table 6-19. Standard attributes, parameters, methods, and references for evaluating the soil component of the ecosystem.

Attribute	Parameter	Method	Reference
Identify	Taxonomic Name	7th Approximation Taxonomy	12[a]
Location and Distribution	Map Scale	Field Survey and Aerial Photointerpretation	8
Depth	Inches;Centimeters	Measuring Tape	8
Horizonation	Various Chemical and Physical Measurements	Various Chemical and Physical Tests Listed Below, Ocular Estimates	2(Parts 1,2), 8,12
Structure	Visual Shape	Ocular Estimate	8
Color	Hue, Value, Chroma	Munsell Color Chart	8,12
Slope	Degrees; Percent	Abney level; Clinometer	8
Aspect	Compass Direction	Compass	8
Degree of Erosion	Qualitative Descriptors	Ocular Estimate	8
Erodibility	Water-K-factor	Universal Soil loss equation	17 18
	Wind-I-factor (Relates to Wind Erodibility Group)	Wind Erosion Equation	
Texture	Percent of Sand, Silt, Clay	Feel Method, Sedimentation Analysis, Direct Seiving	8,12
Organic Matter Content	Percent	Oxidation	2(Part 2)
Parent Material	Qualitative Descriptors	Various Chemical and Physical Tests; Ocular Estimates	2(Parts 1,2), 8
Soil Moisture	Weight Percent; Volume Percent; pF; Bar-percentage	Gravimetric; Neutron Scattering; Tensiometer, Bouyoucos Blocks	2(Part 1)

Table 6-19 (Continued)

Attribute	Parameter	Method	Reference
Moisture Regime	Qualitative Descriptors	Estimated from Climate Data (Precipitation, temperature, potential evapotranspiration) as related to the soil solum	12
Temperature Regime	Degrees	Estimated from climatic data or measured with special thermometer or thermocouple	12
Available Water Capacity	Inches of Water Held Per Inch of Soil	H_2O Content at field capacity H_2O Content at wilting point	2(Part 1)
Permeability	Inches/Hour	Constant Head or Falling Head Method	2(Part 1)
Surface Runoff	Soil Slope, Soil Profile, Climate, Cover	Ocular Estimate	8
Presence of Pans	--	Ocular Observation backed by Various Chemical and Physical Tests	2(Parts 1,2)
Bulk Density	g/cm^3	Core Method	2(Part 1)
Particle Density	g/cm^3	Pycnometer	2(Part 1)
Soil Reaction	pH	pH Meter, Various Chemical Reactants	2(Part 2);8
Sodium Adsorption Ratio (SAR)	None	Chemical Extraction and Computation as $\frac{Na}{\sqrt{Ca+Mg/2}}$	6
Exchangeable Sodium (ESP)	Percent	Chemical Extraction	2(Part 2)
Cation Exchange Capacity (CEC)	Meq/100 g of Soil	Ammonium Saturation Sodium Saturation	2(Part 2)

Table 6-19 (Continued)

Attribute	Parameter	Method	Reference
Total Exchangeable Bases (Base Saturation)	Percent	Chemical Extraction	2(Part 2)
Calcium Carbonate Equivalent (Lime Requirement)	Percent	Barium Chloride Method;Soil pH Method	2(Part 2)
Toxic Elements	Percent;PPM	Various Chemical Analyses Depending on Element or Compound	2(Part 2)
Macronutrient Elements	PPM	Various Chemical Analyses depending on Element or Compound	2(Part 2)
Micronutrient Elements	PPM	Various Chemical Analyses Depending on Element or Compound	2(Part 2)
Depth to Water Table	Inches; Centimeters	Measurement	8,12
Electrical Conductivity	Micromhos/Centimeter	Conductance	6

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[a] References for methods commonly used in the collection and analysis of data on soils for terrestrial baseline studies.

1. Berg 1977
2. Black 1965
3. Brady 1974
4. Buol et al. 1973
5. Bureau of Land Management, Manual Section 7000
6. Salinity Laboratory Staff 1954
7. Singleton and Cline 1976
8. Soil Survey Staff 1951
9. Soil Survey Staff 1960
10. Soil Survey Staff 1962
11. Soil Survey Staff 1967
12. Soil Survey Staff 1975
13. Soil Conservation Service 1967
14. Soil Conservation Service 1976
15. Walsh and Beaton 1973
16. Wilde 1958
17. Soil Conservation Service 1977
18. Chepil 1954

site, evaluating plant distribution and productivity, assessing impact, and designing mitigation procedures. Because soils are among the most important elements of an ecological study, and because they are so complex, an expert is usually required to interpret the data.

Quantitative data may be difficult to obtain at many sites because of the complexity of the soils and the number of attributes to be estimated. Attributes of soil can be highly variable within an area because they are constantly being modified by internal (e.g., chemical and physical alterations) and external (e.g., climate, plants, animals) forces.

Summary. Soils are among the most important components for terrestrial ecological baseline studies. Soils are a primary factor in ecosystem productivity and are important to impact assessments and mitigation planning, especially where revegetation is involved. The state of the art for soils science is well developed for agronomic studies and, to a lesser extent, for commercial forest and rangeland studies. However, knowledge of natural plant productivity in relation to salinity, toxic elements, and other soil characteristics is limited and must be expanded greatly. Because soils studies can become time-consuming, objectives must be clearly established at the beginning of a project.

6.6.3 Hydrology

6.6.3.1 Definition and Purpose. Hydrology is the science that deals with the waters of the earth, their occurrence, circulation, and distribution; their chemical and physical properties; and their reaction with their environment, including their relation to living things (Ad Hoc Panel on Hydrology 1962). In the broad sense of this definition, hydrology is not strictly an abiotic endeavor. This discussion, however, is limited to the relationships between the natural environment, mankind's activities, and water resources.

Frequently the life scientist is faced with analyzing the effect of an activity upon living organisms. Many of man's activities directly affect water quantity, timing of availability, location of availability, and physical and chemical quality. In turn, these effects on water resources directly affect many living organisms. Therefore, it becomes important to understand the mechanisms or processes which dictate how water resources will respond to a perturbation induced by man's activities. The hydrologist is trained to explain the causal relationships between these activities and the natural hydrological processes. Using this explanation, the life scientist can determine the impacts of these activities on living organisms as specifically caused by modifying the natural hydrologic regime.

Because the types of hydrologic investigations required for impact analysis depend on both the nature of the project and the environment, it is impossible to specify a set of procedures that is universally applicable. Nevertheless, it is useful to discuss some general hydrologic programs with biological considerations, to establish a benchmark from which more specific interaction between hydrologist and life scientist can proceed.

Frequently, flows in a stream or river system are depleted by direct removal and/or detention of a portion of the total flow for project use. Animals and plants as well as domestic, municipal, agricultural, and industrial users may be affected by reduced flows. Frequently, timing of flow reduction rather than just magnitude of reduction is of concern. By statistical analysis and streamflow-system-simulation modeling the hydrologist can predict future flows at specified points of interest downstream. From these predictions life scientists can assess actual impacts upon downstream life systems.

Projects involving surface disturbance, such as excavating, paving, building, raw material stock-piling, and modifying topography and vegetation, can result in drastic changes in both quality and quantity of local runoff. The hydrologist can predict what such changes would be and recommend steps to ameliorate them. Life scientists then can estimate impacts based on predicted peak flow rates, sediment loads, and other factors.

Groundwater often plays an important, though sometimes inconspicuous role, in the overall availability of water resources for use by man, animals, and vegetation. Groundwater resources are frequently tapped for project needs. Often, groundwater must be removed to permit surface and underground mining. Groundwaters are also affected by waste-disposal operations. Hydrologists can assess the magnitude and extent of such impacts on local groundwater tables, and whether or not springs, seeps, and surface-stream flows may be affected. Life scientists can then assess impacts upon terrestrial and aquatic ecological systems.

6.6.3.2 Methods. Hydrological studies should be designed to provide necessary data to ecologists and resource specialists who are responsible for analyzing environmental conditions and for predicting effects of future development or changing resource management practices in the area. Reliable calculations of such hydrological parameters as sediment yield, runoff, low streamflow, and flood projections require an extensive data base collected over many years. If such data exist, they are normally available from U.S. Geological Survey offices, from the office of the state engineer, or the Soil Conservation Service. Precipitation records needed for these calculations can be obtained from National Weather Bureau offices. Typical field studies that can be implemented to collect needed hydrological data include measuring streamflow; collecting water samples for sediment or other water-quality parameter analysis; characterizing the drainage basin (describing stream gradients, soil types, vegetation cover, and geomorphological properties); or conducting groundwater surveys to characterize location, quantity and quality of groundwater resources. Because many of these studies involve constructing instream devices (weirs or flumes), drilling monitor wells, or installing automatic recording equipment, they often require a considerable expenditure of time and money. Typical techniques used to perform hydrological studies are detailed in Chow (1964), USDA, Soil Conservation Service (1972), and Davis and DeWiest (1966). Additional methods directly related to properties of streams and lakes are described in Section 6.5.2.

6.6.3.3 Interpretation of Data. Calculations of various hydrological parameters such as runoff, floods, low streamflows, and sediment yield require statistical or other mathematical reduction of data. Chow (1964) describes most of these calculations. Water-quality data can be evaluated by comparing them to state or federal standards or to recommended criteria for various water uses (National Academy of Sciences and National Academy of Engineering 1972). Once all necessary hydrological parameters have been calculated and summarized, the information can be used to assess the biological significance of hydrological conditions on ecosystem components.

Summary

Hydrological studies should be designed to provide needed information for understanding ecosystem stresses and for evaluating impacts of resource developments or changing resource management practices. Because a large and long-term data base is required to calculate many hydrological parameters, many baseline studies will have to rely on data collected by federal and state agencies or by private investigators. If historic data are not available, and knowledge of the particular hydrological parameter is vital for predicting project impacts, a considerable amount of time and money will often be required to obtain a reliable estimate of the parameter. The statistical basis of many hydrological parameters quantifies those parameters and permits us to estimate the uncertainties associated with them. Such quantification and probability estimates allow the life scientist to predict more accurately the impact of hydrological factors on the biota.

7.0 ORGANIZE AND CONDUCT FIELD PORTION OF THE BASELINE STUDY

7.1 INTRODUCTION AND OVERVIEW

This chapter deals with organizing and conducting field studies to complement the existing information base. The steps in the baseline study program described in preceding chapters are necessary precursors to field investigations. Chapter 7 discusses some basic principles by which the field program can be implemented and controlled to assure that it meets its objectives within the targeted time frames and the established budget. The chapter addresses some of the basic concerns of any field project, regardless of size. It does not attempt to go into the details of equipping and coordinating a field team, because these activities are project-specific and should be well within the capabilities of any given project team.

The field program is essentially a project. It is performed by a project team headed by one person, the project manager, who has final decisionmaking authority on all project activities. This is an essential point. The project manager may seek the counsel of his superior, and others, before making a decision, and his decisions may be reviewed by a superior; but the project manager is empowered to act without seeking or awaiting any such input. This chapter is written for the project manager.

7.2 PROJECT INITIATION

Before proceeding further, identify the kinds of expertise needed for each element of the field program and secure the services of a qualified person for each position. This is called staffing. Table 7-1 illustrates the staffing of a hypothetical baseline study team for a major coal-fired power plant.

With the project team, review the total program, making changes in stated objectives and methods of investigation as necessary. Once satisfied that the general plan of attack (methods and experimental designs) will best satisfy objectives, prepare a more detailed plan. Begin by breaking the project into subunits or tasks, based on what makes the most sense: chronology, geography, taxonomy, organizational units, etc. This is called developing the work breakdown structure. Table 7-2 presents a hypothetical work breakdown structure for an ecological baseline study of a major coal-fired power plant.

Table 7-1. Hypothetical staffing for an ecological baseline program for a major coal-fired power plant. This hypothetical example includes only four study programs.

Overall Project Staff

- Project Manager
- Administrative Assistant
- Clerical (Filing, Typing, etc.)
- Graphics Artist

Soil Study Program

- Soil Scientist
- Field Technicians

Vegetation Study Program

- Plant Ecologist
- Plant Pathologist
- Field Technicians

Wildlife Study Program

- Wildlife Biologist
- Herpetologist
- Ornithologist
- Invertebrate Biologist
- Animal Pathologist
- Field Technicians

Aquatic Study Program

- Fisheries Biologist
- Invertebrate Biologist
- Phycologist
- Water Chemist
- Field Technicians

Next, prepare a matrix listing the work breakdown elements along the vertical dimension (down the side) and persons responsible along the horizontal (across the top). At each appropriate intersection, or cell, identify those having responsibility for a given work element. Consider the type of responsibility involved (e.g., obtaining equipment, performing field work, quality assurance, data analysis, interpretation, review). This is called a responsibility matrix. Figure 7-1 presents an example responsibility matrix for the wildlife portion of an ecological baseline study for a major coal-fired power plant.

Use the responsibility matrix as a basis for developing a detailed, written plan of attack. Each element of the work breakdown structure is now scheduled, budgeted, and coordinated in schedule and cost with all other work breakdown elements. On complex projects, the resulting master schedule can be refined and better coordinated through a critical path analysis. The result is a graphic, time-based network showing which activities must precede others (task series), which activities may be done concurrently (in parallel), and which activities are most critical in terms of time. It is on these last activities that you, the project manager, must focus your most intensive monitoring and control efforts.

As an important aside, it should be noted that participation of each team member in this planning process is essential. For one thing, this assures that the project receives maximum benefit from the expertise on the team. (The manager never knows more than the collective knowledge of his team, so he should not do all the planning). More important, it is through the give and take of this planning and scheduling process that you reach agreement with each team member about his role on the project. On the basis of this agreement, you can reasonably expect a firm commitment from each team member to meet the agreed-upon performance standards, both within the specified time frame and for the specified costs (or level of effort). If these requirements are satisfied for each element of the work, the objectives will be met and the project will be successful.

Finally, make certain to disseminate the written plan, and check that each team member understands his or her role in contributing to the total project. Most projects that fail to attain their objectives do so either because the objectives were not clearly defined in the first place, or because the objectives and the means for achieving them were not clearly communicated. A published project plan is an effective communications tool for implementing a project and, if updated, for assuring that the project team remains on target throughout the program.

7.3 PROJECT EVALUATION AND CONTROL

7.3.1 Unforeseen Difficulties

Not all contingencies can ever be foreseen during project planning. Therefore, as the project proceeds, the unexpected is bound to require changes in the project plan. The trick is to adapt the plan in a way that minimizes deviation from the targeted objectives. Thus, the plan must be flexible enough to permit problems to be addressed and solved as they arise. (A "problem" is any unexpected deviation from the plan.) Your basic job as project manager is to coordinate this problem-solving effort.

Table 7-2. Hypothetical work breakdown structure for an ecological baseline program for a major coal-fired power plant

Major Task	Subtask
Project Administration	Schedule Control Budget Control Communication Report Review Personnel Evaluation Typing
Soils Study Program	Soils Mapping and Series Characterization Soil Sample Collection Data Analysis
Vegetation Study Program	Vegetation Mapping Productivity Sampling Ponderosa Pine Foliar Damage Sampling Sagebrush Water Stress Evaluation Data Analysis
Wildlife Study Program	Small Mammal Relative Abundance Estimation (Field) Small Mammal Physiology/ Histology Program Mammalian Predators (Scent Station Program) Large Mammal/Raptor Aerial Surveys Sage Grouse Aerial and Ground Surveys Night Owl Surveys Qualitative Avian Surveys Qualitative Herpetofauna Surveys Leaf Litter Terrestrial Invertebrate Surveys Ponderosa Pine Insect Infestation Data Collection Wildlife Data Analysis

Table 7-2 (Continued)

Major Task	Subtask
Report Production	Report Preparation Graphics Typing Proof-reading Printing Binding

	Wildlife Biologist	Herpetologist	Ornithologist	Invertebrate Biologist	Animal Pathologist	Field Techniques
Small Mammal Relative Abundance	X					X
Small Mammal Physiology/Histology					X	
Mammalian Predators	X					X
Large Mammal/Raptor Aerial Surveys	X		X			
Sage Grouse Surveys			X			X
Night Owl Surveys			X			X
Qualitative Avian Surveys			X			
Qualitative Herpetofauna Surveys		X				
Leaf Litter Invertebrate Surveys				X		X
Ponderosa Pine Insect Infestation Survey				X		X
Data Analysis	X	X	X	X	X	X
Report Preparation	X	X	X	X	X	

Figure 7-1. An Example Responsibility Matrix. The matrix identifies the persons responsible for completing specific work elements of the wildlife portion of an ecological baseline study.

Deviations may be beneficial or detrimental. If beneficial, make adjustments to take full advantage of the change. If damaging, adjust to recoup, or at least minimize, the losses.

7.3.2 A Management Information System

In order to solve a problem, you must first perceive that there is a problem. Feedback from the management information system provides that perception. This system reports to you what the actual accomplishments and expenditures are relative to your plan at a given point in the schedule. The faster this information is reported, the faster your adjustments (solutions) will be.

Major problems with management information systems include (1) slow response times (such as a manager learning of a cost overrun weeks after it occurred), and (2) a lack of clear correlation between cost and work completed at a given point in the schedule. For example, a budget report from the accounting department might show that you spent the money you expected to spend by a given time, but it might not show that only two-thirds of the work scheduled for completion by that time is actually finished. The budget report, therefore, indicates that you are on target, when in fact, you are actually behind schedule and over budget. The best way to avoid this problem is with a system that integrates both cost and schedule, so that you can evaluate expenditures against value earned.

Such an information system derives from a project plan that has:

(1) Divided the work into short, discrete packages of assigned work (work packages).

(2) Provided specific responsibility for the work packages within the project organization.

(3) Scheduled each work package, providing measurable end points or completion milestones as a basis for measuring work accomplishment.

(4) Provided estimates of cost for each work package.

(5) Assured that work packages with meaningful milestones are assigned to the lowest formal level of organization.

If this has been done, you can trace accomplishments by completed work packages, and compare task completions with expected versus actual expenditures.

For example, the management information system for an ecological baseline study allows a dollar comparison, at any point in time, between the work scheduled to be completed by that date and work actually completed by that date. This information is provided in three types of data:

(1) BCWS -- budgeted cost of the work scheduled to date.

(2) BCWP -- budgeted cost of the work performed to date.

(3) ACWP -- actual cost of work performed to date.

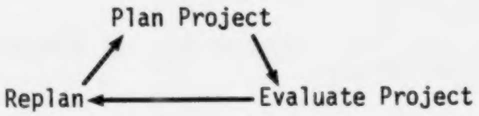
From these data, you can derive three other important types of information:

(1) Schedule Variance = BCWP - BCWS. This variance, in dollars, is the difference between work planned and work accomplished. A positive value suggests that you are ahead of schedule; a negative value, that you are behind.

(2) Cost Variance = BCWP - ACWP. This is the difference between dollars planned and dollars expended for the work accomplished. A positive value indicates that you are within your budget; a negative value, a cost overrun.

(3) Estimated Cost at Project Completion = $\frac{\text{ACWP}}{\text{BCWP}}$ x total budget. To estimate total anticipated cost underruns or overruns, subtract this value from the total budget.

Variances detected by the above procedures can be traced back through the work breakdown structure to the packages and individuals responsible. Here you may need to make some adjustments. Remember, to be successful, a project must operate within finite limits. If the project is on schedule but over its budget, you must either obtain new funds (change the finite limits), or make internal changes. Internal changes mean altering the schedule, the technical performance standards, or both. As long as the original limits remain, a change in one element of the project (performance, schedule, or cost) requires adjustment in one or more of the others. The process described here can be diagramed:



However, with a good management information system, you can go immediately to the person or persons responsible to seek a solution to the problem. You can minimize this type of confrontation, however, by keeping team members involved in the planning process. Members who helped plan the project and their own assignments on that project are usually at least as concerned as you are when problems with their tasks arise. Generally they will be highly motivated to help find a solution. This kind of accountability is essential to the successful completion of any project.

If, on the other hand, you have imposed the standards of performance, schedule, and cost upon the team member without really consulting him, he may not have a solid commitment to the project. You then must deal with a personnel problem in addition to the problem of cost. The implications of this kind of atmosphere to the success of a project are obvious.

7.4 PROJECT TERMINATION

Once the field program has accomplished its objectives, terminate it clearly. Assign appropriate team members to analyze and interpret the data in such a way that the data from the field program can serve as input into the decision process, along with the conceptual model and supporting materials. How this is done is described in Chapter 8.

8.0 INTERPRET BASELINE RESULTS FOR DECISIONMAKERS

8.1 INTRODUCTION AND OVERVIEW

A baseline study begins by defining the decisionmaking framework -- finding out what decision will be made and what information is needed for sound decisionmaking. The objectives of the baseline study are based on these information needs, and field and literature investigations are designed accordingly. The final step in any baseline study is to "close the loop" by interpreting the results of the baseline study for decisionmakers.

Effective communication is essential if the baseline study results are to have an influence on decisionmaking. It is not sufficient just to present the results of the baseline program; you must explain their meaning. Interpretation implies a responsibility for putting together an effective presentation that relates directly to the information needs of the decisionmaker. There are three important guidelines to keep in mind:

1. The central purpose of any baseline study is to provide the best possible input to the decisionmaking process.

2. You, the ecological investigator, are responsible for providing information that enables decisionmakers to understand the ecological consequences of the proposed project.

3. You must demonstrate to the engineer, the developer, and the decisionmaker that you do, in fact, have something to say worth listening to.

These guidelines should direct your thoughts and actions whenever you communicate with decisionmakers.

8.1.1 When Should Baseline Results Be Communicated?

The open planning necessary to effective baseline study implies that communication should occur whenever necessary throughout the energy development program. This is a valid goal which, if kept in mind, will help ensure that the studies produce the information needed to make intelligent decisions. However, there will likely be only a few times during the baseline study wherein formal presentations of information are required. One of these will be at the end of the baseline program when a detailed environmental report will probably be required (see Figure 1-1). Another may be at the time when a site is selected. Other interim reports may be required, depending on the objectives and duration of the baseline study and on the nature of the decisionmaking process. Only the final report is discussed in detail here, as it will be the most comprehensive report required. However, the comments are generally applicable to interim reports as well.

8.1.2 What Should Be Communicated to Decisionmakers?

Answering the question of what information should be communicated to whom is not easy. You must walk a careful line between giving the decisionmaker so much information that he cannot absorb it all (even if all of it is pertinent), and giving him a condensed report that lacks proper supporting data, analysis, and interpretation. Any presentation of baseline results requires careful organization and distillation of information so that only the most relevant is presented. How it should be presented is also a question that must later be answered.

Although the specifics of a final presentation depend on the goals and objectives of the study, most baseline reports will have many similarities in the information they present and the way that information is organized.

8.1.2.1 General Types of Information. Holling (1977) lists four general kinds of information that should be conveyed: (1) the data base, including both actual measurements and assumptions; (2) the technical methods used in gathering and analyzing data, and the assumptions underlying each method; (3) the results of the study; and (4) the conclusions. The last two are especially important, because the results and conclusions each have two components: there is the literal component, or the actual numbers, and the "believability" component, or the degree to which the numbers are reliable (Holling 1977).

8.1.2.2 Focusing the Information. Just as most baseline study final reports are likely to include the above types of information, many of them will also organize that information similarly. Nearly all reports will cover the following six areas:

1. Answers to decisionmakers' questions. Relate one section of the final baseline report directly to the questions and concerns of decisionmakers. If a question was raised repeatedly in the course of defining the decisionmaking framework (Chapter 2), the baseline study results should formulate a specific answer to that question. For example, if decisionmakers at the beginning of the project were concerned about trace-element effects on vegetation, and studies were designed to investigate current trace-element loads and predict effects, the baseline report should present this information as a straightforward response to the concern.

2. Description of the proposed development. Most baseline reports require a description of the proposed development. This should explain clearly the potential relationship between development facilities and activities and the surrounding ecosystems. Do not attempt to reiterate engineering plans, but include information on

location of facilities, scheduling, development phases, major activities, and potential environmental perturbations of the development.

3. Description of existing ecological conditions. Describe the existing ecological conditions and trends for the future. This is one of the traditional sections of a baseline report. However, the focus should be changed. Describe the status of a few selected species or resources that are of particular importance, e.g., game species, threatened and endangered species, etc. Then concentrate effort on the fundamental systematic properties of higher levels of biological organization, communities, ecological response units, or even whole ecosystems. Use the conceptual model to illustrate the functional relationships between components, their important interactions and interdependencies, and the key processes and information flows that regulate the system. Clearly explain the total picture.

4. Predicted impacts of the proposed development. Design this section to assess ecological impacts within a total socioenvironmental framework. You can subdivide this section to correspond to several of the common sections of an Environmental Statement under NEPA, including those listed in Chapter 1. Use the conceptual model for the cause-and-effect reasoning necessary for assessing impacts.

5. Preliminary recommendations for mitigation and monitoring. Although the formal preparation of mitigation plans and monitoring programs is outside the purview of the baseline study, a report on baseline conditions contributes heavily to these later stages of a total ecological studies program. The members of the study team will have extensive knowledge of the ecological conditions, the development plans, and the potential impacts of development activities. Their preliminary ideas for mitigation and monitoring should be included in the final report.

6. Documentation. A final baseline report must not only present and interpret the results of the study, but should also document the study process. The rationale for selecting attributes, for selecting methods to measure and analyze data, and for analyzing impacts must be well-documented. The results and conclusions of baseline studies will likely be incorporated into applications for permits and licenses. Should court action be taken for any reason, documentation will become especially important.

8.1.3 How Should Baseline Results Be Communicated?

Results of the study should be presented in a way that allows the audience to understand and believe the information presented. How this is done often depends on the audience. As a first step in defining how information ought best to be presented, answer questions like the following:

1. Who is my audience?

2. What role does the audience play in the decisionmaking process?

3. What kind of technical training or experience does my audience have?

4. How much time will the audience be allowed to absorb the information presented?

Aim your main presentations at the primary decisionmakers. If you communicate effectively to them, you will have accomplished your most important task.

8.1.3.1 Written Reports. The traditional means of communicating baseline results is the detailed report on ecological conditions. This will continue to be the most important means of communication, because of legal requirements and tradition, because of the need for documentation of the entire baseline study process, and because a written report is relatively easy to disseminate to a large audience. For this reason, only written reports are discussed in detail here.

Although written baseline reports have sometimes failed to communicate effectively in the past, they can be effective if prepared correctly. To produce a useful document, follow a few basic rules of writing:

1. Direct the report to a specific audience.

2. Include only pertinent information.

3. Organize information so it is readily accessible.

4. Be concise.

5. Use appendices for extensive discussion, large data tables, and detailed descriptions of methodology.

6. Pay attention to form and style.

Strunk and White (1959), Council of Biology Editors (1972), and Office of Biological Services (1977) are three good references. Consult them for suggestions on how to prepare a good document. The first, entitled The Elements of Style, is particularly good at providing, in a very few pages, a great deal of guidance on how to write effectively.

8.1.3.2 Other Types of Presentations. The written report is not the only technique available. Other methods may be more effective in special circumstances, such as two techniques that Holling (1977) proposes. The first is the workshop, or interactive technique. Instead of merely giving the decisionmakers a report on baseline conditions, invite the decisionmakers to a workshop, where they participate in analyzing and interpreting the results.

For example, Holling (1977) uses computer simulation as a predictive tool in environmental assessment. In order to communicate an understanding of the model to the decisionmaker, he invites the decisionmakers to workshops where they are able to sit down at a computer terminal and try out different model assumptions or environmental management options. The exercise produces three main benefits. First, it gives the decisionmaker an understanding of the structure that produces predictions. Second, he can alter model assumptions to see how sensitive the predictions are to changes in these assumptions, to uncertainties in the data, and to uncertainties in the implementation of the policies. Third, the decisionmaker learns to develop a feeling for how much confidence he should have in the predictions.

This interactive technique could also be used with the conceptual model produced in Chapter 4. For example, decisionmakers could meet in small groups with the baseline study team, and explore the nature of the various portions of the conceptual model. The impact matrix, process diagrams, and system control diagrams can be used to estimate impacts of development activities throughout the system (see Section 4.1.4). Providing decisionmakers the opportunity to trace for themselves the chain of effects through the system will certainly increase their understanding of the potential consequences of the energy development program.

The second of Holling's (1977) techniques is the narrative slide presentation. A 10- or 15-minute slide presentation can convey a great deal of information because it is short and to the point. It does not overwhelm with numbers or confuse with jargon, and it holds the attention of the audience (Holling 1977). A slide presentation that focuses on limited areas of concern, such as the current status of a deer herd and predicted effects of development on it, could be a very useful communication tool.

A third communications technique, graphics, should be used in conjunction with the written report. Wherever possible, summarize information in tabular or graphical form. Many of the types of diagrams presented earlier in this manual (flow diagrams, process diagrams, system control diagrams, and matrices) are useful for summarizing results as well. Also include maps and overlays so the reader can tell where the facility will be located, where different ecological response units are located, and where important species are distributed.

One other graphical technique that is particularly useful is the impact "tree" or network. This type of figure is used to show the chain of effects from development activities in the ecosystem. The system control diagrams also accomplish this; however, they are often large and complex. The network is simpler because it includes only those portions of the system control diagram affected (directly or indirectly) by a particular perturbation.

Figure 8-1 presents an example impact network developed from the system control diagrams for an oil shale development in western Colorado (C-b Shale Oil Venture 1977). Figure 8-2 presents an alternate way to use an impact network. This example shows the relationships between a development activity, environmental perturbations, and the effects of the perturbation, both direct and indirect.

8.2 PLAN THE REPORT

When planning the outline, focus on the stated objectives of the baseline program and orient the interpretive efforts toward meeting those objectives.

If more than one report or presentation is required, decide what presentations will be presented to whom. Next, prepare a preliminary outline for each presentation. The outline directs the interpretive efforts by becoming a focal point for the project team.

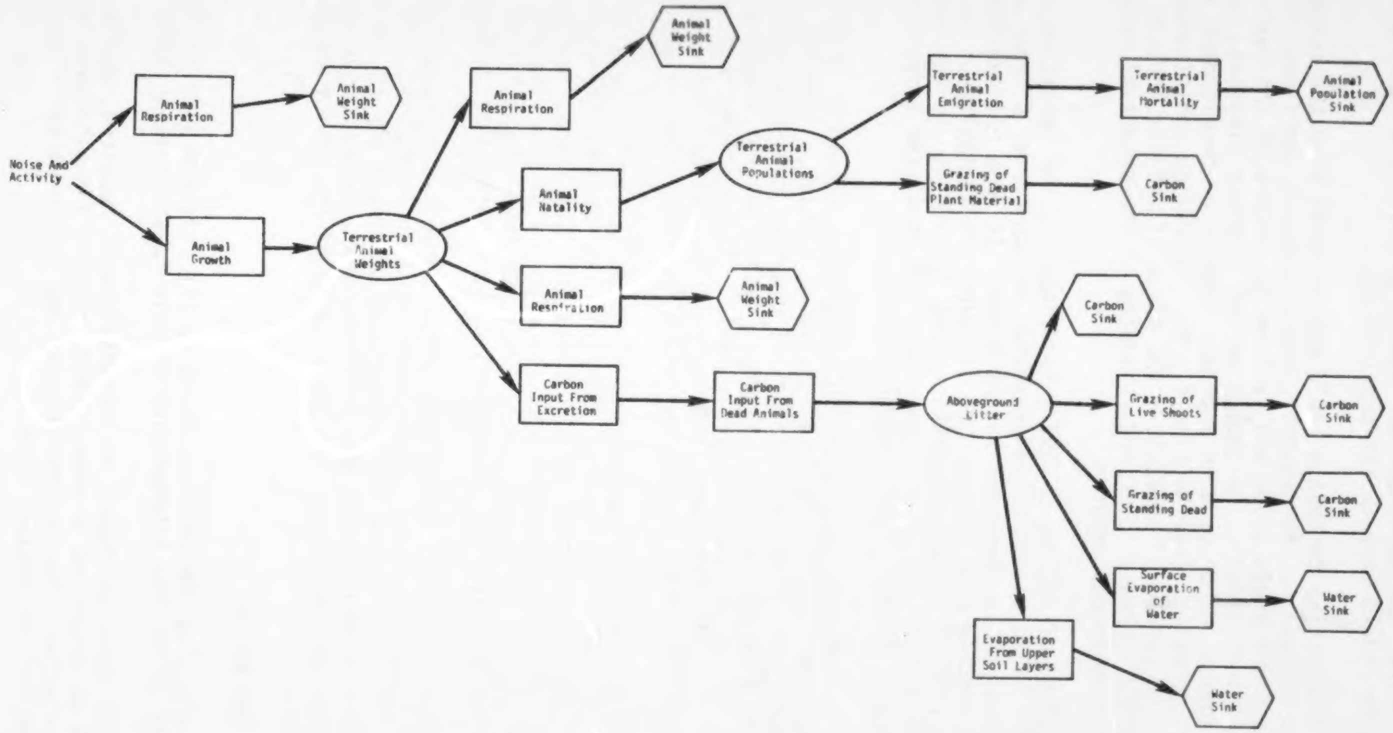

Noise And Activity
Animal Respiration
Animal Weight Sink
Animal Growth
Terrestrial Animal Weights
Animal Respiration
Animal Weight Sink
Animal Natality
Animal Respiration
Animal Weight Sink
Carbon Input From Excretion
Terrestrial Animal Populations
Terrestrial Animal Emigration
Terrestrial Animal Mortality
Animal Population Sink
Grazing of Standing Dead Plant Material
Carbon Sink
Carbon Input From Dead Animals
Aboveground Litter
Carbon Sink
Grazing of Live Shoots
Carbon Sink
Grazing of Standing Dead
Carbon Sink
Surface Evaporation of Water
Water Sink
Evaporation From Upper Soil Layers
Water Sink

Figure 8-1. Example Impact Network. This diagram traces the chain of effects resulting from noise and activity associated with an oil shale development in western Colorado. The network was developed through tracing the effects on a very large system control diagram developed in C-b Shale Oil Venture 1977. Rectangles are ecosystem processes, circles are ecosystem components, and hexagons are "sinks" outside the boundaries of the system.

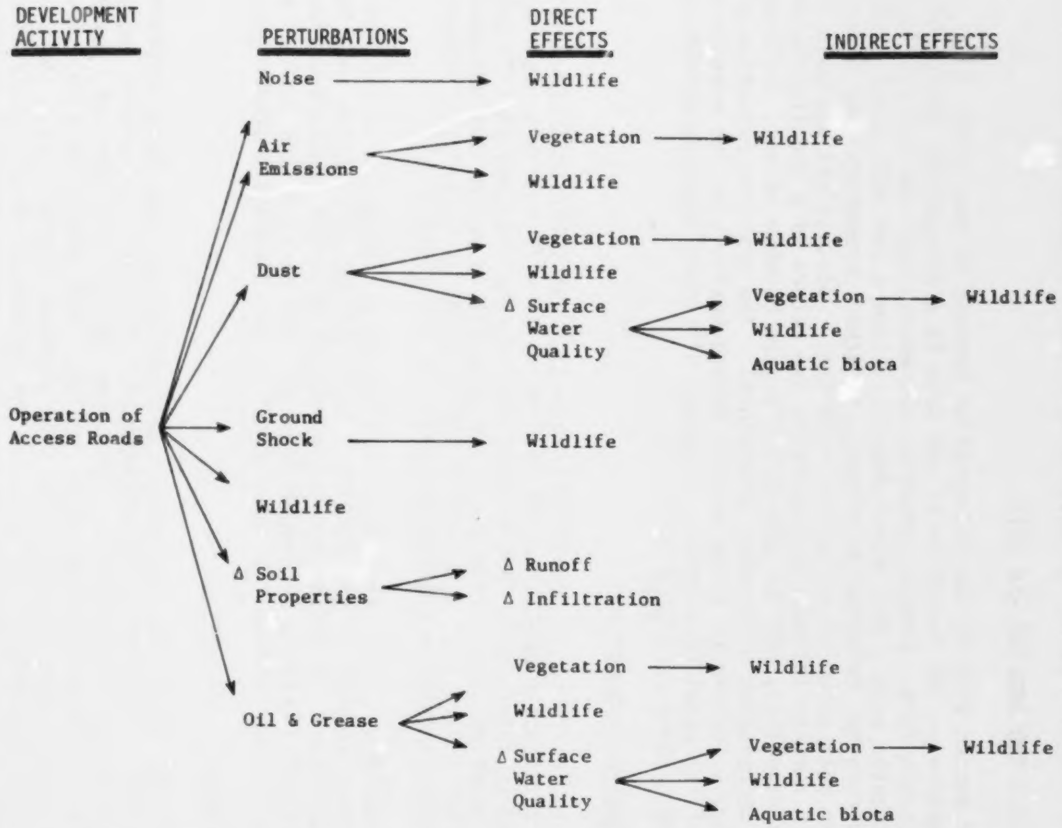

DEVELOPMENT ACTIVITY
PERTURBATIONS
DIRECT EFFECTS
INDIRECT EFFECTS
Operation of Access Roads
Noise
Wildlife
Air Emissions
Vegetation
Wildlife
Wildlife
Dust
Vegetation
Wildlife
Wildlife
Δ Surface Water Quality
Vegetation
Wildlife
Wildlife
Aquatic biota
Ground Shock
Wildlife
Wildlife
Δ Soil Properties
Δ Runoff
Δ Infiltration
Oil & Grease
Vegetation
Wildlife
Wildlife
Δ Surface Water Quality
Vegetation
Wildlife
Wildlife
Aquatic biota

Figure 8-2. An alternate example of the use of an impact network. This example illustrates the impacts associated with a major development activity (Operation of Access Roads) of surface coal mines. From: Moore and Mills 1977.

8.2.1 An Example Outline For A Baseline Report

General topics of baseline reports were presented in Section 8.1.2 above. The specific outline will be determined by the objectives of the baseline program. As such, the example outline presented in Table 8-1 should be used only as a starting point for developing a specific detailed outline.

8.3 REDUCE AND ANALYZE RAW DATA

The second step in the interpretive process is one common to any scientific investigation -- the reduction of raw data to a manageable, analyzable, and interpretable form. Common reduction procedures call for calculating quantitative estimates (e.g., population density, biomass per unit area), indices (e.g., diversity, relative abundance), or other parameters that effectively summarize data about an ecological component. Statistical analysis is used to obtain further information regarding the nature of a specific parameter (e.g., variability, real or chance difference between values, confidence limits, correlation with other parameters). The specific reduction procedures and analysis techniques to be applied depend entirely on the experimental design of the baseline program. A number of general considerations regarding these topics were presented in Chapter 6.

8.4 ORGANIZE INFORMATION

Early in the study, existing information about the proposed development and the socioenvironmental system with which it will interact was compiled and organized (Chapter 3.0). Additional studies were designed to fill gaps in this information base. This step is essentially a review and reiteration of the earlier activities, with effort now directed at organizing information so it can best be interpreted and presented to decisionmakers.

To do this, first categorize information as discussed in Section 8.1.2 within the framework of the outline. Then arrange information in a format that facilitates inspection and comparison of data and indentification of important relationships between data sets. Use various aids such as maps and overlays, lists, tables, matrices, figures, and diagrams wherever possible.

8.5 INTERPRET INFORMATION

Once the reduction, analysis, and organization have been completed, you can begin the accompanying interpretation. Assemble the various sections of the report as much as possible. Then work through the sections, summarizing and explaining highlights for each section. This should be a relatively straightforward task for the first five sections (Table 8-1). The next three sections may require more effort, but the conceptual model constructed early in the design of the baseline program should provide powerful assistance.

8.5.1 Refine The Conceptual Model

After baseline data have been reduced and analyzed, check the validity of the conceptual model against field results. Go through the procedures in Chapter 4.0 again, revising the various materials in light of new information and site-specific data. The goal of this iterative process is to refine the conceptual model so that it illustrates, to the maximum extent possible, your understanding of the structure and function of the ecosystem(s).

8.5.2 Describe Current Ecological Conditions

A major function of Section VI in the proposed outline (Table 8-1) is to build a picture of the ecosystem. That picture already exists in the form of the conceptual model. As constructed, the model is a conceptual replica of the ecosystem. The development of the model began by examining separately the structural elements of the system (the components) and the functional elements of the system (the processes). Next, to link the components and processes, the model identified flows between components and examined processes controlling these flows. Finally, the entire system was reconstructed conceptually, using information linkages between various flow subsystems. By tackling the system one step at a time, starting with the simplest elements and showing how they fit together to form the whole, the extreme complexity of an ecosystem was thus reduced to comprehensible dimensions.

Section VI of the report can, therefore, meet its goal of describing both structure and function of the existing ecological system, if it presents the model in a manner that is understandable to the decisionmakers. The numerous lists, diagrams, flow charts, and matrices that constitute the model will be useful only if they are accompanied by careful explanation. To do this, explain the most important portions of the model in relatively simple, nontechnical terms. Explain how each piece was developed, why it was chosen, and what it contributes to our understanding of the ecosystem.

8.5.3 Use the Conceptual Model to Predict Impacts

Section VII of the suggested outline for a baseline report (Table 8-1) assesses the ecological impacts of the proposed development. The conceptual model of the system provides a number of tools to aid the systematic examination of cause-and-effect relationships necessary for assessing impacts. These tools enable one to:

1. Consider systematically and individually the possible impacts of development activities.

2. Estimate which impacts will occur out of all the possibilities considered.

3. Trace the effects of direct impacts throughout the system.

4. Apply a semiquantitative value reflecting the relative seriousness of each impact.

Section 4.1.4 of this manual discusses how to use the impact matrix, the process diagrams and the system control diagram in identifying and tracing impacts. Refer to this section and use the conceptual model to identify and trace impacts.

8.5.4 Develop Preliminary Recommendations for Mitigation and Monitoring

After estimating impacts from the proposed development activities, use the list of impacts to develop preliminary recommendations for mitigating those impacts. This mitigation is primarily the responsibility of the developer.

Table 8-1. An example outline for a final baseline report

I. Front Matter
  A. Table of Contents
  B. List of Tables
  C. List of Figures

II. Executive Summary
  (Brief discussion of the contents of each chapter in the report)

III. Introduction and Purpose
  A. Introduction to and Purpose of the Document
  B. Introduction to the Baseline Program
    1. Purpose of the Baseline Program
    2. Goals of the Baseline Program
    3. Objectives of the Baseline Program

IV. Description of the Proposed Development
  A. Geopolitical Region
  B. Major Characteristics
    1. Time Schedule
    2. Zone of Influence
    3. Inputs, Outputs, and Facilities
  C. Expected Environmental Perturbations

V. Major Concerns Identified by Decisionmakers
  A. Concern 1
    1. Study Programs Designed to Address Concern
    2. Methodology Used
    3. Results
    4. Conclusions (including statements on the degree of belief one should have in the conclusions)
  B. Concern 2
    (Same as above)
  C. Concern 3
    (Same as above)

VI. Description of the Existing Ecological Conditions
  A. Status of Important Species or Communities
    1. Socioeconomically Important
    2. Unique
    3. Aesthetically Valuable
    4. Threatened or Endangered
  B. Structure and Function of the Ecosystem(s)
    1. Ecological Response Units, Description and Rationale
    2. Ecologically Important Components
    3. Ecologically Important Processes
    4. The Impact Matrix
    5. Process Control Diagrams for Critical Processes
    6. System Control Diagrams

Table 8-1 (Continued)

VII. The Ecological Impacts of the Proposed Development
    A. Method of Assessing Impacts
        1. Impact Matrix
        2. Process Control Diagrams
        3. System Control Diagrams
    B. Impacts of Particular Concern
    C. The Relationship Between Local Short-Term Uses of the Environment and the Maintenance and Enhancement of Long-Term Productivity
    D. The Irreversible and Irretrievable Commitments of Resources Which would be Involved in the Proposed Action should it be Implemented

VIII. Preliminary Recommendations for Mitigation and Long-Term Monitoring

APPENDICES
    A. Detailed Methodology Descriptions
    B. Documentation for Subjective Judgments
    C. Glossary

You can use the conceptual model to decide what to monitor in order to determine how effective the mitigation efforts will be. The model diagrams should identify how an impact moves through the system. Determine how best to monitor that impact by tracing it through the system using the diagrams. Monitor the process or component of the ecosystem that is most likely to show the effects of that impact earliest.

For example, the concentration of certain heavy metals in animal tissues may produce sublethal effects on reproduction or behavior. By the time these effects appear in animal populations, however, the pollutants will very likely have contaminated the system quite thoroughly. Using the model, it can be determined, for instance, that the heavy metals originate from a smokestack. They are transported through the air, washed into the soil by rain, taken into the plant by roots, and assimilated into herbivores through grazing. The first place these contaminants may be detected is in the air, and the second is the soil. This information tells the investigator to monitor the air, or possibly, the soil for heavy metals. If such monitoring is too costly, perhaps plant tissue analyses will provide the information soon enough to protect the animals.

Working through the conceptual model to determine where monitoring efforts should be is very similar to using the model for identifying major impacts. It is both art and science, and it requires expertise in many disciplines to identify specific effects on different processes and components of the ecosystem.

APPENDIX A

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Literature Cited

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APPENDIX B
Glossary

Introduction

This glossary was prepared as part of a U.S. Fish and Wildlife Service project to clarify and standardize the purpose and practice of ecological baseline studies for energy-development activities in the western United States. It is intended for persons who must design or evaluate ecological baseline studies, and for those who must make decisions based upon baseline study results.

Because a multidisciplinary approach is demanded by many of these activities, the glossary includes terms and definitions from several disciplines commonly associated with ecological baseline study or energy development. Only the major interfaces between the various environmental sciences and energy-development activities have been addressed. The principal objective of the glossary is to increase the efficiency of the multidisciplinary communication necessary for effective baseline study. As such, the glossary is intended as a communications tool that can help biologists, engineers, planners, and regulatory and conservation agency personnel to communicate through a common language.

The sources consulted to obtain terms included professional ecologists, engineers, and other environmental scientists, as well as the literature. (See "Sources" at end of glossary.)

Likewise, many candidate terms were considered, but only those contributing to the above-stated objectives were selected. As a general criterion, words thought to be commonly misunderstood among different disciplines were included in the glossary. The names of organisms were excluded because they can be found easily in dictionaries and standard reference texts. Broad classifications of "types" of organisms (e.g., rough fish; phytoplankton) are included, however, because such terms are commonly used but rarely defined for the benefit of nonbiologists involved in baseline studies. Units of measurement were excluded because their definitions are straightforward and readily available in standard references. Terms useful in communicating the recommended conceptual framework of ecological baseline studies have been included since it is important that practitioners understand the "why" as well as the "what" of ecological baseline studies.

The following rules are applied to achieve consistency in organization:

1. Terms appear in alphabetical order. The alphabetizing is both straightforward and fractured, i.e., "index of relative abundance" appears under "index of relative abundance" as well as under "abundance, index of relative." Definitions are presented with only one listing.

2. In general, nouns with adjective modifiers are entered under the noun if there are several phrases having that noun as the base word (e.g., impact, acute; impact, chronic; etc.); otherwise an adjective-noun combination that commonly stands alone is entered under the "key" word in the phrase.

3. Synonyms are listed in parentheses after main (capitalized) terms.

4. Sources of definitions are listed in each definition, by number in the case of published sources, by name in the case of unpublished sources. The source, "ECI", indicates the definition was written by the project team. Definitions having published reference sources may appear slightly changed from their form in the source document according to the evolving meaning of the term. The complete list of sources appears at the end of the glossary.

5. When necessary to distinguish between closely related definitions or to pursue terms related to the ideas expressed by the term of concern, the reader is advised to see a related term, unless the related term appears in the definition at hand, in which case the related term is underlined. Words used in definitions that are themselves defined elsewhere in the glossary are underlined.

The definitions presented are in accord with common usage, but it has been impossible to present all the nuances of meaning possible for any one term. The rapidly changing nature of the sciences that contribute to ecological baseline studies and the concomitant rapid changes in the associated language preclude the pairing of terms and definitions that will be viewed as accurate by all. In addition, the richness of our language imparts a wide range of flexibility to most terms, and it is not our intent to deny such depth by implying that the definitions presented here represent the only contexts in which the terms should be used. A short addendum at the end includes words that were suggested too late for alphabetical insertion.

ABATEMENT
The controlled reduction of pollutant emissions. (00)

ABIOTIC FACTOR
See FACTOR, ABIOTIC ENVIRONMENTAL

ABSORPTION
The penetration of one substance into or through another. For example, in air pollution control absorption is the dissolving of a soluble gas from an emission into a liquid as a means of removing that gas from the air stream. See ADSORPTION; SORPTION. (01)

ABSORPTIVE TERRACE
See TERRACE, ABSORPTIVE

ABUNDANCE, INDEX OF RELATIVE
A measurement of relative abundance. Some commonly used indices are "frequency" or the percent of sample plots in which the species occurs, abundance or the percent of individuals in a sample, and cover or the percent of ground surface covered as determined by projection of aerial parts onto the ground. (02; 03)

ABUNDANCE, RELATIVE
The number of individuals of a species in a given time and place relative to the number of individuals of the same species in another time or place. See DENSITY, RELATIVE. (04)

ABUNDANCE, SPECIES
An estimate of the total number of individuals of a species in a defined area, volume, population, or community. See DENSITY. (02; 04)

ACCLIMATION
Physiological or behavioral adjustment or compensation in response to a defined environmental variable (e.g. heat, cold or salinity). Sometimes used interchangeably with acclimatization. (04)

ACCLIMATIZATION
Physiological or behavioral adjustment or compensation in response to the entire set of variables in a natural environment (e.g. acclimatization to winter). Sometimes used interchangeably with acclimation. (04).

ACCURACY
Accuracy, in the general statistical sense, denotes the closeness of an estimate to the true value it is estimating. (05)

ACID MINE DRAINAGE
See MINE DRAINAGE, ACID

ACID RAIN
Rain that has a depressed pH due to the presence of hydrolyzed end products from oxidized sulfur or nitrogen and halogen compounds. (00)

ACID SPOIL
See SPOIL, ACID

ACCUMULATIVE ECOLOGICAL IMPACTS
See IMPACT(S), ACCUMULATIVE ECOLOGICAL

ACUTE IMPACT
See IMPACT, ACUTE ECOLOGICAL

ACUTE TOXICITY
See TOXICITY, ACUTE

ADAPTABILITY
The ability of an organism to alter its physiology or behavior in order to compensate for environmental changes. (Strickland)

ADAPTABLE
Capable of undergoing inheritable and/or noninheritable structural or functional changes in response to environmental changes that could otherwise impair life processes. (06)

ADAPTATION
A change in the structure, physiology or behavior of an organism that increases the overall compatibility of the organism with its environment. Adaptations are generally thought of in two time frames: 1. long-term evolutionary adjustment of a population to environmental changes, or 2. short-term physiological or behavioral responses. See ACCLIMATION; ACCLIMATIZATION. (06)

ADDITIVE EFFECTS
The combined effects of more than one pollutant acting simultaneously or in succession to give a total effect equal to the sum of the independent effects. See EMERGENT PROPERTIES: SYNERGISTIC EFFECTS; ANTAGONISM. (27)

ADSORPTION
The adherence of the atoms, ions, or molecules of a gas or liquid to the surface of another substance (the adsorbent). Adsorption is often used to extract pollutants by causing them to be attached to adsorbents such as activated carbon or silica gel. Some adsorbents are used to extract oil from waterways in oil spills. See ABSORPTION; SORPTION. (07; 08)

AERATION
The process of being supplied or impregnated with air. Aeration is used in waste water treatment to foster biological and chemical purification. (01)

AEROSOL
A suspension of liquid or solid particles (in a gas) of such size that they tend to remain suspended for an indefinite period. (08)

AFFORESTATION
The artificial establishment of forest crops by planting or sowing on land that has not previously, or not recently, grown tree crops. See REFORESTATION. (09)

AFTERBURNER
An air pollution abatement device that removes undesirable organic gases through incineration. (01)

AFTERDAMP
Toxic mixture of gases produced by a coal mine fire, an explosion, or the partial burning of substances used in breaking down coal. (08)

AGE CLASS
A general term applied to organisms that are born, hatched, etc. within the same specified time period. Age-class time frames may vary with generation time of the organisms of concern; for example, the "young," "juvenile," and "adult" age classes of many small mammals occur within a single year, whereas for many species of trees the "young" age class alone encompasses several years. (ECI)

AGE DISTRIBUTION (Age Class Distribution)
The classification of individuals of a population according to age classes or age-related periods such as "prereproductive," "reproductive," and "postreproductive." (02)

AIR CONTAMINANT
Any foreign material in the air; that is, material other than oxygen, nitrogen, the noble gases, water vapor, and carbon dioxide. (08)

AIR CURTAIN
A method for mechanical containment of oil spills. Air is bubbled through a perforated pipe causing an upward water flow that retards the spreading of oil. Air curtains are also used as barriers to prevent fish from entering a polluted body of water. (01)

AIR GASIFICATION
Partial combustion; the process by which coal is burned with about one-half of the air needed for complete combustion, producing a nonfuel gas consisting mostly of carbon monoxide, a fuel species, and nitrogen. Used widely by industry in electric power generation during the 1920's. Heating value is 1/6 that of natural gas. (08)

AIR POLLUTION
The action of making air physically impure or unclear; contaminating air with man-made waste. (08)

AIR POLLUTION CONTROL REGIONS
Geographical areas designated by governmental agencies for the purpose of establishing air pollution standards and control. (00)

AIR POLLUTION EPISODE
A period of sustained high levels of atmospheric pollution often coinciding with periods of thermal inversions and low wind speeds. (00)

AIR QUALITY, AMBIENT
Condition or quality of the surrounding air. (00)

AIR QUALITY CRITERIA DOCUMENTS
A compilation by the federal government of the published information on a given pollutant and its adverse effects on man and his environment. (00)

AIR SAMPLING
The collection and analysis of air samples for detection or measurement of radioactive substances, particulate matter, or chemical pollutants. (08)

ALGAL BLOOM
A proliferation of algae on the surface of lakes, streams, or ponds, which is stimulated by nutrient (often phosphate) enrichment. (08)

ALLUVIUM
Material such as earth, sand, gravel, or other rock or mineral materials transported by and deposited by flowing water. (09)

AMBIENT AIR QUALITY
See AIR QUALITY, AMBIENT

AMPLITUDE, ECOLOGICAL
The range of environmental conditions in which an organism or a life process can function. See TOLERANCE. (02; Strickland)

ANALYSIS OF VARIANCE
A statistical procedure for separating the total amount of variation in a set of data into components and assigning each component to a specific source. Judgments can then be made as to whether a particular source of variation is due to an effect or to chance. (05)

ANALYSIS, STATISTICAL
The analysis of data, based on certain assumptions, that will give some conclusion about the data along with some measure of probability concerning the correctness of the conclusion. (ECI)

ANGLE OF REPOSE
The greatest angle from the horizontal at which any loose or fragmented solid material will stand without sliding after coming to rest when poured or dumped in a pile or on a slope. (09; Strickland)

ANGLE OF SLIDE
The degree of slope at which loose or fragmented materials will start to slide. A slightly greater angle than the angle of repose. (09; Strickland)

ANIMAL UNIT CONVERSION FACTOR
A figure for calculating the carrying capacity of local vegetation that allows conversion from one kind or class of animal to another. Such a conversion factor is applicable to the amount of forage required to maintain an animal, but it may have no application in determining stocking rates for range use for particular kinds or classes. (10)

ANIMAL UNIT MONTH (A.U.M)

The quantity of forage required by one mature cow (1000 lb.) or its equivalent for one month. (10)

ANTAGONISM

When two or more pollutants act simultaneously or in succession to produce a total effect that is less than the sum of their independent effects. See ADDITIVE. (00)

ANTHRACITE (Hard Coal)

Generally a hard, black, lustrous coal containing a high percentage of fixed carbon and a low percentage of volatile matter. (08)

AREA MINING

Surface mining that is carried on in level to gently-rolling topography on relatively large tracts. (09)

AREA SOURCE

In air pollution, an extended region or area such as a mine or a city wherein a relatively large number of individual sources contribute to a more or less homogenous mixture of pollutants. See POINT SOURCE; NON-POINT SOURCE; LINE SOURCE. (ECI)

AQUIFER

A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield quantities of water to wells and springs. (11)

ASH

Inorganic residue remaining after ignition of combustible substances. (08)

ASPECT

The direction toward which a slope faces measured in azimuth (e.g., 135°) or compass points (N, NW, etc.). Since plants suffer their greatest moisture losses through evapotranspiration on southwest-facing slopes (which receive the greatest energy input from the sun compared to that received by other slopes), aspect can be an important factor influencing vegetation distribution. (09)

ASSESSMENT

See ENVIRONMENTAL IMPACT ASSESSMENT

ASSIMILATION

Absorption of ingested material into the body of an organism; as opposed to that part of the material defecated. (Gaud)

ASSIMILATIVE CAPACITY

Capacity of a water body to receive, dilute, and carry away wastes without harming water quality; in the case of organic matter, also includes the capacity for natural biological oxidation, which may be expressed in pounds per day at a specific river flow rate and temperature. (08)

ASSOCIATION

A term with a number of usages, so the intended definition should be given whenever this term is first used.

1. The occurrence of species together. (Strickland)

2. Often used to denote a commonly occurring relationship between two or more species that can be readily recognized in the field and treated as an ecological unit. (ECI)

3. A community, stand, or group of organisms characterized by a definite floristic composition, presenting uniform physiognomy and structure, and growing under uniform habitat conditions. (ECI)

4. In an abstract sense, a group of communities or stands that are classified together because they meet certain standards of similarity. (ECI)

ASSOCIATION, INDEX OF

A measure of the occurrence together of one species with another, calculated by dividing the number of samples in which one species occurs by the number of samples in which both occur. (02)

ATTRIBUTE

In the context of systems ecology, a characteristic of a component. The sum of our knowledge of all attributes defines the component, e.g., attributes of grass include color, phenology, live biomass, dead biomass, litter biomass, etc. See PARAMETER; COMPONENT; PROCESS. (ECI)

AUGER MINING

Generally practiced in but not restricted to hilly coal-bearing regions of the country. Utilizes a machine based on the principle of the auger, which bores into an exposed coal seam, conveying the coal to a storage pile or bin for loading and transporting. May be used alone or in combination with conventional surface mining. When used alone, a single cut is made sufficient to expose the coal seam and provide operating space for the machine. When used in combination with surface mining, the last cut pit provides the operating space. (ECI)

AUTOTROPH

Organisms capable of constructing organic matter from inorganic matter. (06)

AVERAGE

Generally an average is considered to be a single representative description of a set of values. In this sense it would include the median and the mode. Most often the average is assumed to be the arithmetic mean. (04; 12)

BACKFILL

The operation of refilling an excavation. Also the material placed in an excavation in the process of backfilling. (09)

BACKGROUND CONCENTRATION
See BACKGROUND LEVEL.

BACKGROUND LEVEL (Background Concentration)
The natural or normal concentration of a substance in air, water, or soil. (Strickland)

BAGHOUSE
An air pollution abatement device used to trap particulates by filtering gas streams through large fabric bags, usually made of glass fibers. (01)

BASELINE STUDY, ECOLOGICAL
Any investigation conducted prior to the "breaking of ground" in order to provide an ecological basis for decisions on whether, where, and how to accomplish a proposed development. The scope of study may range widely, from qualitative inventories conducted by natural resource managers to exhaustive quantitative studies of specific development sites undertaken by industry in compliance with federal and state regulations. The results of an ecological baseline study describe the existing ecological conditions and trends in the potentially affected region, providing a reference "baseline" from which environmental scientists can (1) predict the effects of the proposed action and recommend alternatives, (2) define appropriate mitigation measures, and (3) design future programs to monitor the accuracy of predictions and the effectiveness of mitigation. (ECI)

BENCH
The surface of an excavated area located at some point between the material being mined and the original surface of the ground on which equipment can set, move or operate. A working road or base below a highwall as in contour stripping for coal. (09)

BENCH METHOD, EXTENDED
See SURFACE MINING, EXTENDED BENCH METHOD

BENCH TERRACE
See TERRACE, BENCH

BENEFICIAL IMPACT
See IMPACT, BENEFICIAL ECOLOGICAL

BENEFICIATION
The process by which the heating value of coal is increased by the removal of the noncoal components of the raw material. (Roop)

BENTHOS
The animal and plant life that inhabit the bottom of the sea, a lake, a stream or some other aquatic habitat. (08)

BERM
1. A narrow shelf, path, or ledge typically at the top or bottom of a slope. (13)

2. In coal mining such a strip of coal may be temporarily left in place as a location on which hauling and stripping machinery can be operated. (ECI)

3. Also, a layer of relatively heavy, stable material placed at the outside bottom of a spoil pile to help hold the pile in position. (09)

4. Diking around ash disposal areas at power plants is sometimes called a berm. (ECI)

BIAS

A characteristic of a sampling system. It consists of the average of the errors of the estimate of a parameter taking into account the direction of the errors. Bias represents a systematic error which occurs in the sampling program. (ECI)

BINARY CYCLE

An energy recovery system that results in heat exchange between two separate fluid-circulation systems. The purpose of a binary cycle is to obtain higher efficiencies from the energy source. (08)

BIOACCUMULATION (Biological Accumulation)

The ability of an organism to concentrate a substance throughout its active metabolic lifetime so that the concentration factor, if calculated, would be continuously increasing during the lifetime of the organism. See BIOCONCENTRATION; BIOMAGNIFICATION. (08)

BIOASSAY

1. Determination of the physiological effect of a substance (such as a drug) by comparing its effects on a test organ or living organism with that of some standard substance. (06)

2. Determination of the concentration of a substance (e.g., a pesticide residue) in the tissues of an organ or organism. (ECI)

BIOCHEMICAL OXYGEN DEMANDS

See OXYGEN DEMAND, BIOCHEMICAL

BIOCONCENTRATION (Biological Concentration)

The active concentration of a substance (molecule or compound) by an organism as a result of normal activities, e.g., absorption or ingestion. See BIOACCUMULATION; BIOMAGNIFICATION. (06)

BIOCONVERSION

The conversion of one form of energy into another by plants or microorganisms. (08)

BIODEGRADATION

The biochemical breakdown of complex, large, organic molecules into small simple molecules; decomposition by bacteria, fungi, and other microorganisms. (08)

BIOLOGICAL DIVERSITY
See DIVERSITY, BIOLOGICAL

BIOLOGICAL HALF-LIFE
The time required for a biological system (such as a human or animal) to eliminate, by natural processes, half the amount of a substance (such as a radioactive material) that has entered that system. (08)

BIOLOGICAL INDICATOR
See INDICATOR, BIOLOGICAL

BIOLOGICAL OXYGEN DEMAND
See OXYGEN DEMAND, BIOLOGICAL

BIOLOGICAL PARAMETER
See PARAMETER, BIOLOGICAL

BIOMAGNIFICATION (Biological Magnification, Bioamplification)
The step-by-step concentration of substances in successive trophic levels of food chains; commonly reported only for harmful substances (e.g., pesticide residues). See BIOCONCENTRATION; BIOACCUMULATION. (06)

BIOMASS
The total weight of living and dead matter in organisms, often expressed per unit volume or area. (04)

BIOMETRY (Biostatistics)
The statistical study of biological phenomena; the application of mathematics to the analysis of living things. See STATISTICS. (14)

BIOMONITORING
The use of living organisms to test the suitability of effluent for discharge into the environment or to test the air or water quality at some specified distance from the pollutant's source. See BIOLOGICAL INDICATOR. (01)

BIOSPHERE
The portion of the earth and its atmosphere capable of supporting life. (08)

BIOSTATISTICS
See BIOMETRY, STATISTICS

BIOSYNTHESIS
The process by which living organisms convert one form of matter, usually simple compounds, into more complex substances. (08)

BIOTA
All of the named or namable organisms of an area; fauna and flora (= biota) of a region. (06)

BIOTIC COMMUNITY
See COMMUNITY, BIOTIC

BIOTIC FACTOR
See FACTOR, BIOTIC ENVIRONMENTAL

BIOTIC POTENTIAL
1. The intrinsic rate of population increase. (04)

2. The inherent ability of a population to grow in the absence of external controlling factors. (04)

BIOTYPE
A genetically homogeneous population; a genotypic race or group of organisms. See ECOTYPE. (06)

BITUMINOUS COAL (Soft Coal)
The most important and plentiful rank (type) of coal. Bituminous coal is the chief fuel in steam-electrical plants and is used in many other industrial processes. (08)

BLOCK CUT METHOD
See SURFACE MINING, BLOCK CUT METHOD

BLOW DOWN
1. The process whereby five to ten percent of the water within a wet-type cooling tower is continually drained off and replenished with a fresh supply to prevent the excessive concentration of certain salts, minerals, and other constituents within the system. (Stevens)

2. To a forester, "blow down" refers to trees or portions of trees downed by storms. (Bromeshenk)

BOX CUT
In surface mining, the initial cut made at a mining site that results in a highwall on the upslope side and a lowwall barrier on the downslope side. (09)

BREEDER REACTOR
A nuclear reactor that produces more fuel than it consumes. (01)

BROADCAST SEEDING
Scattering seed on the surface of the soil. Contrasts with drill seeding which places the seed in rows in the soil. (09)

CARRYING CAPACITY
The maximum density (or biomass) of a given species in a given area beyond which no significant increase can occur without damage occurring to the resources upon which the population depends. (06)

CATALYTIC HYDROGENATION PROCESS
A method for adding hydrogen to substances using a catalyst to promote the reaction. It can be used to convert coal to a liquid and/or to

remove sulfur from residual ore, coal, crude coal liquids, and coal extracts. (08)

CATCHMENT AREA
See DRAINAGE BASIN

CHEMICAL OXYGEN DEMAND
See OXYGEN DEMAND, CHEMICAL

CHEMICAL STRATIFICATION
See STRATIFICATION, CHEMICAL

CHI-SQUARE STATISTIC
In general usage, any statistic that has an approximate chi-square distribution. Most familiar occurrences are in goodness-of-fit or contingency table analysis where comparison is made between counts actually observed in each of several classes and expected counts in each class under a particular hypothesis. (04; 05; 12)

CHRONIC IMPACT
See IMPACT, CHRONIC ECOLOGICAL

CHRONIC TOXICITY
See TOXICITY, CHRONIC

CLIMAX COMMUNITY
See COMMUNITY, CLIMAX

CLINE
A continuous series of differences (structural or functional) exhibited by a group of related organisms, usually along a line of geographic or environmental gradient. (06)

COAL
A solid, combustible, organic material formed by the decomposition of vegetable material without free access to air. Chemically, coal is composed chiefly of condensed, aromatic ring structures of high molecular weight. (08)

COAL CONVERSION
The conversion of coal to a liquid or gas suitable for use as a fuel. (08)

COAL GASIFICATION
The conversion of coal to a gas suitable for use as a fuel. (08)

COAL LIQUIFICATION (Coal Hydrogenation)
The conversion of coal into liquid hydrocarbons and compounds by hydrogenation. (08)

COAL SEAM
A bed of coal that is usually thick enough to be profitably mined. (08)

COAL SLURRY
A mixture of crushed coal and water, or other liquid, which can be pumped. (ECI)

COAL-SLURRY PIPELINE
A pipeline that transports pulverized coal suspended in water. (08)

COEFFICIENT
In a mathematical expression, a numerical term other than a state variable or component. (Gaud)

COEFFICIENT OF HAZE (COH)
A measurement of visibility obstruction based on the quantity of smoke and dust in 1,000 linear feet of air. (00)

COEFFICIENT OF PERMEABILITY
See PERMEABILITY, COEFFICIENT OF

COEFFICIENT OF VARIATION
A statistic used to standardize the variance in a population as compared to its mean. It is the standard deviation divided by the mean, often multiplied by 100 to express as a percentage. (04; 05; 12)

COMMUNITY, BIOTIC
1. The living portion of an ecosystem. (03)

2. An assemblage of interacting populations living in a prescribed area or physical habitat. (03; 04)

COMMUNITY, CLIMAX
The final or stable biotic community in a successional series (sere); it is self-perpetuating and in equilibrium with the physical environment. (03)

COMPETITION
Rivalry between organisms for a common resource in short supply, in which at least one of the competitors is harmed. Competition may be interspecific (i.e., between two or more species), or intraspecific (i.e., between members of the same species). (04; Strickland)

COMPONENT
In the systems ecology context, an arbitrarily defined unit of a model that is generally an abiotic or biotic feature of the landscape such as a stream, a species, or a group of species. See PROCESS; ATTRIBUTE; PARAMETER.

CONCENTRATION
The amount of a substance occurring in a given amount of air, water, soil, tissue, etc. May be expressed as parts per million, grams per liter, or in other units suitable to the substance of interest. (09)

CONCEPTUAL MODEL
See MODEL, CONCEPTUAL

CONFIDENCE INTERVAL
A calculated interval, having an upper and lower limit, with an attached probability ("alpha"). If many such intervals are calculated in repeated sampling, then on the average, the "alpha" proportion of these intervals will not contain the value being estimated. For example, the most commonly employed "alpha" is 5%. The 95% confidence interval for a quantity being estimated is that range of values outside of which the true value will occur 5% of the time. (04; 05; 12)

CONFIDENCE LIMIT
The limiting values, upper or lower, that form a confidence interval. (05)

CONSERVATIVE POLLUTANT
See POLLUTANT, CONSERVATIVE

CONSUMER
An organism that feeds on other organisms or organic matter. Primary consumers (herbivores) feed directly on plants. Secondary consumers (carnivores) feed on primary consumers. See DECOMPOSER; PRODUCER; TROPHIC LEVEL. (14; Strickland)

CONTINGENCY TABLE
A contingency table is a multiple classification scheme, usually two dimensional, whereby each member of a population may be classified according to a distinct category of each of several, usually two, criteria. (15)

CONTOUR STRIPPING
A type of strip mining that is practiced in areas of steep topography where the mineral seam crops out or approaches the surface at approximately the same elevation along a hillside. (09)

CONTROLLING ENVIRONMENTAL FACTOR
See FACTOR, CONTROLLING ENVIRONMENTAL

COOLING TOWER
A device used to remove excess heat from water. It is used in industrial operations, notably in electric power generation. (01)

COOLING TOWER, DRY-TYPE
Cooling towers in which waste heat is dissipated to the air by conduction and convection rather than evaporation. See COOLING TOWER, WET-TYPE. (16)

COOLING TOWER, MECHANICAL DRAFT
A cooling tower that uses fans to move ambient air through the tower. See COOLING TOWER, NATURAL DRAFT. (16)

COOLING TOWER, NATURAL DRAFT
A cooling tower that depends upon a chimney or stack to induce air movement through the tower. (16)

COOLING TOWER, WET-TYPE

A cooling tower in which cooling water is brought in direct contact with a flow of air and the heat is dissipated mainly by evaporation. See COOLING TOWER, DRY-TYPE. (16)

CORE DRILLING

The process by which a cylindrical sample of rock and other strata is obtained through the use of a hollow drilling bit that cuts and retains a section of the rock or other strata penetrated. (08)

CORRELATION

In its most general sense, correlation denotes the interdependence between values of two or more variables. Put more succinctly, if correlation exists between two variables, information about a value of one variable will provide information about the corresponding value of the other variable.
(ECI)

CORRELATION ANALYSIS

A statistical procedure in which an assessment is made of the relationship between two variables and whether this relationship is significant. In contrast with regression, neither variable is assumed to be mathematically dependent on the other. (04; 12)

COST-BENEFIT ANALYSIS

Economic analysis that yields a ratio between anticipated benefits and costs, thus showing the relative economic efficiency of a project or program. (07)

COUPLING MATRIX

See FLOW MATRIX

COVER, VEGETATIVE (Coverage)

The portion of the ground occupied by a perpendicular projection to the ground from the outline of the aerial parts of plants. (04)

COVER, WILDLIFE

The plants or other objects used by animals for nesting, rearing of young, resting, escaping from predators, or avoiding adverse environmental conditions. (10)

CRITICAL HABITAT

See HABITAT, CRITICAL

CRITICAL VALUE

The critical value is that value of a test statistic that divides the distribution of the statistic into an acceptance region and a rejection or critical region. For each significance level a critical value is obtained, such that test statistic results on one side of the value lead to acceptance of the null hypothesis, while results on the other side lead to rejection. (04; 12; 15)

CUT

Longitudinal excavation made by a strip-mining machine to remove overburden in a single progressive line from one side or end of the property. (09)

CUT AND FILL

Process of earth moving by excavating part of an area and using the excavated material for adjacent embankments or for filling adjacent, previously excavated areas. (17)

CYCLONE COLLECTOR

A device that uses centrifugal force to collect large particulates from polluted airstreams. (01)

DECOMPOSER

A heterotrophic organism, usually a bacterium or a fungus, that breaks down the bodies of dead plants and animals into simple substances usable by green plants. As a group these organisms bring about the mineralization of organic matter. See PRODUCER; CONSUMER; TROPHIC LEVEL. (10)

DECOMPOSITION

See MINERALIZATION

DECREASER

See PLANT SPECIES, DECREASER

DEEP CHISELING

Deep chiseling is a surface treatment that loosens compacted spoils. The process involves digging a series of parallel slots along the contours of the spoils surface. The slots impede water flow and markedly increase infiltration. (09)

DEEP MINING

The exploitation of coal or mineral deposits at depths exceeding about 1,000 feet. (08)

DEGREES OF FREEDOM

In the simplest sense, the degrees of freedom for a statistic correspond to the number of elements of a particular set that are allowed to vary, given certain constraints on the elements. The most familiar example is "n-1" degrees of freedom for the variance of a sample. Given the constraints of the mean being known and the number of elements being known, only "n-1" of the "n" elements may be arbitrarily picked, the "nth" element being totally constrained. (04; 05; 12)

DENSITY (Stand Density)

The number of individuals of a defined group occurring in a specified unit of space; refers to the average distance between adjacent individuals. See ABUNDANCE, RELATIVE. (02; 04)

DENSITY, CRUDE (Absolute Density, Bulk Density)

The number of individuals (or biomass) of a species per unit total space. Distinguished from ecological density. (03; 04)

DENSITY-DEPENDENT FACTOR
See FACTOR, DENSITY-DEPENDENT

DENSITY, ECOLOGICAL (Specific Density)
The number of individuals or biomass of a species per unit of habitat space (available area or volume that can actually be colonized by the population). See ABUNDANCE, RELATIVE; ABUNDANCE, SPECIES; DENSITY, CRUDE. (03)

DENSITY-INDEPENDENT FACTOR
See FACTOR, DENSITY-INDEPENDENT

DENSITY, RELATIVE
1. Density of a given species expressed as a proportion of the total density of all species in the area. (04)

2. Also used to indicate the density of a species at a particular time or in a particular location as a proportion of the total density of that species over all times or locations sampled. (04)

See ABUNDANCE, RELATIVE; ABUNDANCE, SPECIES.

DESULFURIZATION
The process by which sulfur and sulfur compounds are removed, usually by chemical or catalytic processes, from gases or liquid hydrocarbon mixtures. (08)

DETERMINISTIC MODEL
See MODEL, DETERMINISTIC

DETRITUS
The particulate organic matter involved in the decomposition or mineralization of dead organisms. (03)

DIRECT IMPACT
See IMPACT, DIRECT

DISCHARGE (Flow)
The quantity of water moving past a specific point in a stream. Measured by a specific flow-measuring device. (Delfino)

DISCHARGE, THERMAL
A discharge of heat energy from an industrial facility as a by-product of operation (commonly cooling), usually in the form of heated air or water. (ECI)

DISSOLVED OXYGEN
The extent to which oxygen occurs in solution in water or wastewater; usually expressed as concentration, in parts per million, or percent of saturation. (ECI)

DISTRIBUTION, BINOMIAL
The binomial distribution gives the probabilities that 0, 1, 2, ..., n members of a sample of size n will possess a given attribute when the sample is randomly taken from a population in which a proportion "p" of the members possess this attribute and a proportion 1-p do not. See DISTRIBUTION, PROBABILITY. (18)

DISTRIBUTION, NORMAL
A continuous probability distribution completely defined by its mean and variance. It is characteristically bell-shaped and symmetric about the mean. (ECI)

DISTRIBUTION, PROBABILITY
A function that will give the probability of any particular value or set of values occurring. The function is such that all probabilities are greater than or equal to zero and the totality of probabilities of all values is one. (ECI)

DISTRIBUTION, STUDENT'S t
A continuous probability distribution, generally formed from the ratio of a sample mean to a sample variance. It is bell-shaped and symmetrical, like the normal distribution, but its shape depends on the degrees of freedom. It is most commonly used in testing mean differences. (Zar)

DISTURBED LAND
Land that has been altered physically, biologically, or chemically by the action of man; e.g., land on which excavation has occurred or upon which overburden has been deposited. (09)

DIVERSION
Channel constructed across the slope for the purpose of intercepting surface runoff. Changing the accustomed course of all or part of a stream. Also, a ditch or canal by which water is diverted from one stream to another. (17)

DIVERSION DIKE
A ridge of compacted soil placed above, below, or around a disturbed area to intercept runoff and divert it to a disposal area. (17)

DIVERSION DITCH (Diversion Swale)
An excavated, temporary drainageway used above and below disturbed areas to intercept runoff and divert it to a safe disposal area. (17)

DIVERSITY, BIOLOGICAL
The number of species of organisms or the variety of communities or associations per unit area or volume. (06)

DIVERSITY, ECOLOGICAL
The total range in kinds and frequencies of species interactions in a defined area and time period. (ECI)

DIVERSITY, INDEX OF SPECIES
An index of the number and abundance of species in a biotic community. (04)

DIVERSITY, SPECIES
The number and abundance of species in a biotic community. (04)

DOMINANCE, ECOLOGICAL
The condition in communities or in vegetational strata in which one or more species, by means of their number, coverage, or size, have considerable influence or control upon the conditions of existence of associated species. (02)

DOMINANCE, SOCIAL
The determination of the behavior of one or more animals by the aggressive or other behavior of other individuals, resulting in the establishment of a social hierarchy. (02)

DOMINANT SPECIES
See DOMINANCE, ECOLOGICAL

DOSE
A measured concentration of a toxicant for a known duration of time (concentration per unit time) to which a receptor is exposed. (00)

DRAGLINE
An excavating machine that utilizes a bucket which is operated and suspended by means of lines or cables, one of which hoists or lowers the bucket from a boom; the other cable, from which the name is derived, allows the bucket to swing out from the machine or to be dragged toward the machine for loading. The machine usually operates from a highwall. (09)

DRAINAGE BASIN (Catchment Area, Watershed)
The preferred term for that part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water. (19)

DRAINAGE TERRACE
See TERRACE, DRAINAGE

DRIFT
The entrained solids and liquids carried from a cooling tower by the exhaust air. (16)

DRIVING VARIABLE
See VARIABLE, DRIVING

DYSTROPHIC
Pertains to "bog-like" ponds containing yellow or brown water due to high organic-matter content; they are also characterized by low nutrient availability, low species diversity, and high oxygen demand; oxygen is continually very low and pH is often low. (Zar)

ECOLOGICAL AMPLITUDE
See AMPLITUDE, ECOLOGICAL

ECOLOGICAL BASELINE STUDY
See BASELINE STUDY, ECOLOGICAL

ECOLOGICAL DIVERSITY
See DIVERSITY, ECOLOGICAL

ECOLOGICAL DOMINANCE
See DOMINANCE, ECOLOGICAL

ECOLOGICAL EFFECTS
See IMPACT, ECOLOGICAL

ECOLOGICAL EFFECTS, ACCUMULATIVE
See IMPACT(S), ACCUMULATIVE

ECOLOGICAL EQUILIBRIUM
See EQUILIBRIUM, ECOLOGICAL

ECOLOGICAL IMPACT
See IMPACT, ECOLOGICAL

ECOLOGICAL NICHE
See NICHE, ECOLOGICAL

ECOLOGICAL RESPONSE UNIT
A geographical unit of land that (1) possesses common vegetative, topographic, elevational and edaphic or aquatic characteristics, and (2) responds to environmental influences more or less uniformly throughout. It may encompass one or several plant and animal communities. (ECI)

ECOLOGICAL SUCCESSION
See SUCCESSION, ECOLOGICAL

ECOLOGICAL SYSTEM
See ECOSYSTEM

ECOLOGICAL TOLERANCE
See TOLERANCE, ECOLOGICAL

ECOLOGY
The study of the interactions between organisms and their living and nonliving environment (including interactions with each other). (04)

ECOLOGY, SYSTEMS
The application of techniques of systems analysis to ecological problems. See ECOLOGY; SYSTEMS APPROACH. (20)

ECOSYSTEM
An assemblage of living organisms (biotic community) plus their nonliving (abiotic) environment. (03; 04)

ECOSYSTEM DYNAMICS

Characteristic and measurable processes within an ecosystem such as (1) succession; (2) energy flow and nutrient cycling; (3) community metabolism. (06)

ECOSYSTEM RESPONSE UNIT

See ECOLOGICAL RESPONSE UNIT

ECOSYSTEM STABILITY

1. A measure of the tendency of an ecosystem to persist, relatively unchanged, through time. (06)

2. A measure of an ecosystem's resilience to perturbation. (ECI)

ECOTONE (Edge; Transition Zone)

An ecotone is a transition between two or more biotic communities or vegetation types. It is a junction zone or tension belt which may have considerable linear extent but is usually narrower than the adjoining community areas themselves. The ecotonal community commonly contains many of the organisms of each of the overlapping communities and, in addition, organisms that are characteristic of and are often restricted to the ecotone itself. Often, both the number of species and the population density of some of the species are greater in the ecotone than in the communities flanking it. Organisms that occur primarily or most abundantly or spend the greatest amount of time in junctional communities are often called "edge species". The tendency for organisms to occur in different varieties and densities at community junctions is known as the "edge effect." (10; 21)

ECOTYPE

A race or subdivision of a species that is genetically adapted to local habitat and climate. These genetic groups are broader than a biotype and narrower than a species. Ecotypic variation must be considered before transferring information on impacts to a species in one region to the same species in another region because different ecotypes may respond differently to the same level of effect. (06)

EFFECTIVE POROSITY

See POROSITY, EFFECTIVE

EFFLUENT

A discharge of pollutants into the environment, generally used in regard to discharges into waters. (01)

ELECTROSTATIC PRECIPITATOR

An abatement device that removes droplets or particulates from a gas stream by forcing the carrier gas through an electrical field and collecting the charged particles on an electrode. (00)

EMERGENCE

The appearance of a plant above ground after germination in the soil. (Berry)

EMISSION

A discharge of pollutants into the environment, generally used in regard to releases into the atmosphere. See EFFLUENT. (01)

EMISSION STANDARDS

Standards based on the concentration of pollutants that cannot legally be exceeded during fixed time intervals within specified geographic areas and coming from an identified source. (00)

ENDANGERED SPECIES

See SPECIES, ENDANGERED

ENHANCEMENT

Improvement on existing or projected natural biological conditions. (Keenlyne)

ENRICHMENT

The addition of nitrogen, phosphorus, and carbon compounds or other nutrients into a lake or other waterway that greatly increases the growth potential for algae and other aquatic plants. Frequently, enrichment results from the inflow of sewage effluent or from agricultural runoff. See ALGAL BLOOM. (08)

ENTRAINMENT

Biological usage refers to the passage of organisms through the cooling system of, for example, power plants; engineers use it in terms of ambient water being brought into the cooling plumes as the effluents are discharged from power plants. (Cushing)

ENVIRONMENT

The sum of all external conditions and influences affecting the life, development and ultimately the survival of an organism. (04; 08)

ENVIRONMENTAL ANALYSIS REPORT (E.A.R.)

A report on environmental effects of proposed Federal actions that may require an Environmental Impact Statement (EIS) under Section 102 of the National Environmental Policy Act (NEPA). The EAR is an "in-house" document of various degrees of formality that becomes the final document on environmental impacts for those projects that because their effects are minor, do not require a formal EIS. Although not formally prescribed under NEPA, the EAR is the document normally used to determine whether section 102 of NEPA applies to the project in question, and as such is subject to court challenge if no EIS is filed. See ENVIRONMENTAL IMPACT STATEMENT, DRAFT; ENVIRONMENTAL IMPACT STATEMENT, FINAL. (10)

ENVIRONMENTAL FACTOR

See FACTOR, ENVIRONMENTAL

ENVIRONMENTAL IMPACT ASSESSMENT

An evaluation and objective prediction of the environmental impacts of a proposed action using a systematic, interdisciplinary approach that integrates social and natural sciences and environmental design arts. (10)

ENVIRONMENTAL IMPACT STATEMENT (E.I.S.; Environmental Statement; 102 Statement)
A document prepared by a Federal agency in which anticipated environmental effects of a planned federal course of action or development are evaluated. A Federal statute (Section 102 of the National Environmental Policy Act of 1969) requires that such statements be prepared. It is prepared first in draft or review form, and then, in a final form. An impact statement includes the following points:

1. the environmental impact of the proposed action,

2. any adverse impacts that cannot be avoided by the action,

3. the alternative courses of action,

4. the relationships between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity,

5. a description of the irreversible and irretrievable commitment of resources that would occur if the action were accomplished.

Although "environmental impact statement" (EIS) is the popularly used term, some prefer the term "Environmental statement" (ES), feeling that EIS is an inaccuracy due to the negative connotations of the word "impact." Section 102(C) of NEPA mentions that impacts, effects, alternatives, etc. will be contained in the required "detailed statement." Consequently, to name one feature and to exclude others is inaccurate. See ENVIRONMENTAL IMPACT STATEMENT, DRAFT; ENVIRONMENTAL IMPACT STATEMENT, FINAL.

ENVIRONMENTAL IMPACT STATEMENT, DRAFT (D.E.I.S.; Draft Environmental Statement; D.E.S.)
The version of the statement of environmental effects required for major Federal actions under Section 102 of the National Environmental Policy Act (NEPA), and released to the public and other agencies for comment and review. It is a formal document which must follow the requirements of NEPA, the Council on Environmental Quality (CEQ) Guidelines, and directives of the agency responsible for the project proposal. Since the adoption of state and local laws modeled after NEPA, this term has also been used to refer to similar statements required to comply with those laws. See ENVIRONMENTAL IMPACT STATEMENT; ENVIRONMENTAL IMPACT STATEMENT, FINAL. (10)

ENVIRONMENTAL IMPACT STATEMENT, FINAL (F.E.I.S.; Final Environmental Statement; F.E.S.)
The final version of the statement of environmental effects required for major Federal actions under Section 102 of the National Environmental Policy Act (NEPA). It is a revision of the draft environmental impact statement to include public and agency responses to the draft. It is a formal document that must meet legal requirements and is the document used as a basis for judicial decisions concerning compliance with NEPA. This term is also used for similar statements prepared to comply with state and local laws patterned after NEPA. See ENVIRONMENTAL IMPACT STATEMENT; ENVIRONMENTAL IMPACT STATEMENT, DRAFT. (ECI)

ENVIRONMENTAL MONITORING PROGRAM
See MONITORING PROGRAM, ENVIRONMENTAL

ENVIRONMENTAL PERTURBATION
See PERTURBATION, ENVIRONMENTAL

ENVIRONMENTAL REPORT
A broad term encompassing several specific types of environmental reports that have evolved to meet the requirements of Section 102 of the National Environmental Policy Act of 1969. See ENVIRONMENTAL ANALYSIS REPORT; ENVIRONMENTAL STATEMENT; ENVIRONMENTAL STATEMENT, DRAFT; ENVIRONMENTAL STATEMENT, FINAL. (ECI)

ENVIRONMENTAL STATEMENT
See ENVIRONMENTAL IMPACT STATEMENT

EPILIMNION
That region of a body of water that extends from the surface to the thermocline. See HYPOLIMNION, STRATIFICATION, THERMAL. (06; 22)

EQUILIBRIUM, ECOLOGICAL
In environmental science, a dynamic state of balance in which the components of a physical or biological system partition energy flow in a uniform manner such that outflow balances inflow. (Often applied to an animal population at zero growth, to the interaction between predator and prey, to the energy flow through an ecosystem, and to the nutrient cycling pattern of an ecosystem.) (06; Curry)

ERROR, STATISTICAL
In the statistical sense, error is the difference between an occurring value and its expected value and is caused by random variability in the value rather than by measurement error. See ERROR, TYPE I; ERROR, TYPE II. (05)

ERROR, TYPE I
In testing a statistical hypothesis, one of two possible judgments is made. One is to accept the stated null hypothesis, the other is to reject the null hypothesis. If the statistical evidence has caused rejection of the null hypothesis when it is actually true, Type I error has occurred. See ERROR, TYPE II. (05; 12)

ERROR, TYPE II
If statistical evidence has caused acceptance of the null hypothesis when it is actually false, then Type II error has occurred. See ERROR, TYPE I. (05; 12)

ERODIBILITY
The relative ease with which a specific soil type erodes under specified conditions of slope as compared with other soils under the same conditions. (09)

ESTIMATE

Measurements and observations of a particular parameter, process or response. The accuracy and precision of an estimate depend on the instruments employed and the experimental design in which it was obtained. (ECI)

ESTUARIES

Areas where fresh water meets salt water (e.g., bays, mouths of rivers, salt marshes, and lagoons). Estuaries are delicate ecosystems, serving as nurseries and spawning and feeding grounds for a wide variety of marine life and providing shelter and food for birds and wildlife. (08)

ESSENTIAL ELEMENT

A chemical element required by organisms for normal growth, such as the primary essential elements: hydrogen, oxygen, nitrogen, carbon, phosphorus, and potassium; secondary essential elements: sulfur, iron, calcium, and magnesium; and the trace (or minor) elements: such as boron, manganese, copper, zinc, and molybdenum. The trace elements are required in only minute quantities. See TRACE ELEMENTS. (02)

EUTROPHIC

Describing lentic waters rich in dissolved inorganic nutrient materials, highly productive, and exhibiting a paucity or complete lack of oxygen in the bottom waters. See OLIGOTROPHIC; DYSTROPHIC. (06; Van Landingham)

EUTROPHICATION

The normally slow aging process by which a lake evolves into a bog or marsh. During eutrophication the lake becomes so rich in nutritive compounds, especially nitrogen and phosphorus, that algae become superabundant. Eutrophication may be accelerated by enrichment from human activities. (08)

EVAPOTRANSPIRATION

The process by which soil water is depleted through the combined effects of direct evaporation from the soil and transpiration through living plant tissues. (ECI)

EXPERIMENTAL DESIGN

The application of statistical techniques to the collection of data in order to meet certain objectives. The most common objectives are to reduce variability and to remove as many confounding effects as possible in order to make the experiment sensitive to the phenomenon under study. (ECI)

F-STATISTIC

In general usage any statistic that follows the F-distribution. Most familiar occurrences are in the analysis of variance where comparison is made between two estimates of variability to determine if they are different. In this way, hypotheses about differences among means may be tested. (05; 12)

FACTOR, ENVIRONMENTAL

Any component of the environment that influences the life of an organism or group of organisms. Environmental factors can be either biotic (caused by organisms) or abiotic (caused by nonliving environmental components such as climate, soil, etc.) (02)

FACTOR, CONTROLLING ENVIRONMENTAL
One or more limiting factors or conditions influencing an organism or assemblage of organisms in a way that accounts for a large part of the observed behavior and distribution of that biological entity. (02)

FACTOR, DENSITY-DEPENDENT
An influence on a population, the intensity of which is proportional to the population density (biotic factors such as predation and competition). (Zar)

FACTOR, DENSITY-INDEPENDENT
An influence on a population, the intensity of which is not related to the density of individuals in the population (physical factors such as weather). (Zar)

FACTOR, LIMITING ENVIRONMENTAL
An environmental influence that exceeds the limit of tolerance of an organism and acts as the primary factor restricting its functions, activities or geographic distribution. See FACTOR, CONTROLLING; TOLERANCE, ECOLOGICAL. (02)

FALL OVERTURN
See OVERTURN, FALL

FIELD CAPACITY (Field-Moisture Capacity)
The quantity of water that can be permanently retained in the soil in opposition to the downward pull of gravity. (19)

FISH, GAME (Sport Fish)
A species of fish considered to possess sporting qualities on fishing tackle. Examples of fresh water game fishes are salmon, trout, grayling, black bass, muskellunge, walleye, northern pike, and lake trout. See FISH, ROUGH. (22)

FISH, ROUGH
In a contemporary sense, those species not usually pursued for their sporting qualities. See FISH, GAME. (Heggen)

FLOW CURRENCY
In systems ecology, the particular form of matter or energy that flows between ecosystem components. Common flow currencies are carbon, nitrogen, phosphorus, water, and heat. (ECI)

FLOW CURRENCY SUBSYSTEM
The pattern of flow within ecosystem components for a particular flow currency. For example, carbon flows within the plant biomass or within the animal biomass. (ECI)

FLOW DIAGRAM

A diagram that illustrates the structure of a system in terms of the flow of matter, energy, information, or other materials through that system. These diagrams are useful ways of organizing information. They are used as bases for simulation models. (09)

FLOW MATRIX

See MATRIX, FLOW

FLUE GAS (Stack Gas)

The gases resulting from combustion of a fuel. (08)

FLUSHOUT

An accumulation of water that is removed suddenly from surface-mined lands by heavy precipitation. Such water may contain contaminants in sufficient concentration to result in pollution of the receiving stream. (09)

FLY ASH

Particulates that are carried by the stack gases and released from the stacks of coal-fired electrical generating facilities. The elemental composition of the fly ash is a function of the composition of the coal that is being burned. (ECI)

FOOD CHAIN

The transfer of food energy from the initial source in plants through a linear series of organisms by repeated eating and being eaten. "Food chains" are not isolated sequences but are interconnected with one another to form food webs. See FOOD WEB. (21)

FOOD WEB

The interlocking pattern of food chains that results from their interconnection with one another and that illustrates the multi-path transfer of energy in an ecosystem. (21)

FOSSIL FUEL

Naturally occurring substances derived from plants and animals that lived in ages past. The bodies of these long-dead organisms have become recoverable fuel that can be burned. Fossil-fuels include lignite, coal, oil, and natural gas. (08)

FREQUENCY INDEX

Any measure of the likelihood of encounter of a particular species during a specified sampling procedure. Provides a representation of the spatial distribution of the species. (Gaud)

FREQUENCY, RELATIVE

The proportion of samples in which a given species occurs; the probability of the species occurring in a sample. (04)

FREQUENCY, SPECIES

The absolute number of samples in which a given species occurs. (04)

GAME FISH
See FISH, GAME

GAME SPECIES
See SPECIES, GAME

GAS, NATURAL
A naturally occuring mixture of hydrocarbon gases found in porous geologic formations beneath the earth's surface, often in association with petroleum. (The principal constituent of natural gas is methane.) (08)

GAS, SYNTHESIS
A method of developing liquid fuels from coal by oxidation. (08)

GERMINATION
The breaking of the seed coat followed by the protrusion of the hypocotyl (that part of the axis of a plant embryo or seedling below the first leaf of pair or whorl of leaves developed by the embryo of a seed plant) to form a root system. See EMERGENCE. (Tueller)

GOODNESS OF FIT
In general, the agreement between an observed set of values and a corresponding set of values that is derived wholly or partially from assumptions or hypotheses. The goodness of fit is often measured by the chi-squared statistic, employing the squares of differences between observed and theoretical values. (21; 33; 34) (04; 05; 12)

GOUGING
The process of making numerous small basins in the soil for the purpose of capturing precipitation for increased soil moisture and reduction of erosion. (ECI)

GRADE
1. Common usage: The inclination or slope of a stream channel or ground surface, usually expressed in terms of the ratio or percentage of number of units of vertical rise or fall per unit of horizontal distance. (09)

2. The finished surface of a road bed, top of an embankment, or bottom of an excavation. (09)

3. To establish a profile by backfilling. (09)

GRADIENT
A more or less continuous and unidirectional change of some property in space. Gradiants of environmental properties are ordinarily reflected in changes in biological parameters along the gradient. (06)

GRAPHICAL MODEL
See MODEL, GRAPHICAL

GROSS PRODUCTIVITY
See PRODUCTIVITY, GROSS PRIMARY

GROUND WATER

Subsurface water occupying the saturation zone (where all openings in soils and rocks are filled), from which wells and springs are fed. In a strict sense the term applies only to water below the water table. (06; 10)

HABITAT

The place, and the characteristics and conditions of that place, where an organism lives. (Strickland)

HABITAT, CRITICAL

Any air, land, or water area, including any elements thereof, that the Secretary of the Interior, through the Director, U.S. Fish and Wildlife Service or National Marine Fishery Service, has determined is essential to the survival of wild populations of a listed species or to its recovery to a point at which the measures provided pursuant to the Endangered Species Act of 1973 are no longer necessary. Such determinations are published in the Federal Register. (23)

HAUL ROAD

Road from pit to loading dock, ramp, or preparation plant used for transporting mined material by truck. (09)

HEAD OF THE HOLLOW (Valley Fill Method)

A valley fill method for surface-mined land in which overburden material from adjacent contour or mountain top mines is placed in compacted layers in narrow, steep-sided hollows so that surface drainage is possible. (09)

HEAVY METALS

Metallic elements of high molecular weight, generally toxic to plant and animal life in low concentrations. Such metals are often residual in the environment and exhibit biological accumulation. Examples include mercury, chromium, cadmium, arsenic, and lead. (08)

HETEROTROPH

Organisms that must obtain their food from living or dead organic matter. See AUTOTROPH. (06)

HIGH-LEVEL POLLUTION

See POLLUTION, HIGH-LEVEL

HIGHWALL

The unexcavated face of exposed overburden coal in a surface mine or the face or bank on the uphill side of a contour strip mine excavation. See SURFACE MINING. (09)

HOLISM

The doctrine that the universe, including life in all its forms and the inorganic environment, is correctly seen in terms of interacting wholes that are more than the mere sum of elementary parts. See EMERGENT PROPERTIES. (02; 20)

HOMEOSTASIS

The maintenance of a high degree of constancy in functions of an organism or interactions of individuals in a population or community, under changing environmental conditions, because of the capabilities of organisms to make compensatory adjustments. (02)

HYDRIC

Characterized or pertaining to conditions of abundant environmental moisture supply. See XERIC; MESIC. (06)

HYPOLIMNION

The deep layer of a lake lying below the thermocline and removed from surface influences such as direct heating by sunlight and aeration by vertical circulation. See EPILIMNION. (06; 24)

HYPOTHESIS, STATISTICAL

A tentative assumption about the distributional characteristics of a set of data that can be examined by a statistical test. (04; 05; 12)

IMPACT

An observed effect that occurs in an ecosystem as the result of an environmental perturbation. (ECI)

IMPACT, ACCUMULATIVE

The total effect over time resulting from the sum of the variety of environmental perturbations produced by one facility (i.e., energy-development project). See IMPACTS, AGGREGATE. (Beeton)

IMPACT, ACUTE

Ecological effects commonly resulting from a high level of disturbance but of short duration. (ECI)

IMPACT, AGGREGATE

The sum of a variety of environmental changes and their total effect resulting from several facilities (i.e., energy-development projects) over time. See, IMPACT, ACCUMULATIVE. (ECI)

IMPACT ASSESSMENT

See ENVIRONMENTAL IMPACT ASSESSMENT

IMPACT, CHRONIC

Ecological effects commonly resulting from low levels of disturbance that persist over long periods of time. (ECI)

IMPACT, DIRECT (Primary Impact)

Direct or primary impacts are those in which the causative agent impinges directly upon the responding ecological components, e.g., land clearing for construction causes direct loss of vegetation. (25)

IMPACT, ECOLOGICAL

The observable effects, or suspected effects, of one or more perturbations on the biota of an environmental system. (ECI)

IMPACT, INDIRECT (Secondary or Tertiary Impact)

Indirect or secondary effects are those in which man-caused change in the environment creates one or more intermediary effects in a chain of events leading to the observation of the impact. Certain agencies (e.g., EPA) distinguish between indirect and secondary impacts. For example, an indirect impact occurs when construction of a dam causes reduction of stream flow, which in turn causes elimination of riverine wetlands downstream. Secondary impacts occur when a wastewater treatment project induces urbanization which, in turn, has environmental impacts. (25)

IMPACT, LONG-TERM AND SHORT-TERM

These terms refer to the relative duration of an impact. No strict definition of the relative time frames involved in short- and long-term impacts exists, so a time frame should be specified whenever either word is used. Generally, long-term impacts are those lasting for the duration of the project or longer. Short-term impacts are generally those lasting only during the construction phase or occurring for brief periods during the operation of the facility. (ECI)

IMPACT MITIGATION

See MITIGATION, IMPACT.

IMPACT(S), MODERATE AND SEVERE

Moderate and severe effects are gradations of adverse impacts. Moderate can be characterized as partial elimination, dislocation, impairment, or alteration of biota or use of resources and facilities. Severe can be characterized by total elimination, dislocation, impairment, or alteration of biota or use of resources and facilities. (25)

IMPACT, SIGNIFICANT

Any impact resulting in measurable changes in indicator parameters or community dynamics (such as reduced primary production). See INDICATOR, BIOLOGICAL; COMMUNITY, BIOTIC. (ECI)

IMPACT STATEMENT

See ENVIRONMENTAL IMPACT STATEMENT.

IMPINGEMENT

The term used by aquatic biologists to refer to incidents in which fish become caught and held by water flow against intake screens such as those utilized in power-plant cooling systems. (ECI)

IMPOUNDMENT

A body of water formed by collection and confinement of stream flow (as in a reservoir). (13)

INCREASER

See PLANT SPECIES, INCREASER

INDEX OF ASSOCIATION

See ASSOCIATION, INDEX OF

INDEX OF RELATIVE ABUNDANCE
See ABUNDANCE, INDEX OF RELATIVE

INDEX OF SPECIES DIVERSITY
See DIVERSITY, INDEX OF SPECIES

INDICATOR, BIOLOGICAL

1. An organism that exhibits identifiable responses to a pollutant at low levels; ideally, the responses can be quantified and used to predict what may happen to other, less sensitive, associated organisms at higher stress levels. (ECI)

2. A species whose presence or absence may be characteristic of environmental conditions in a particular habitat. (ECI)

INDICATOR, CHEMICAL (Indicator Parameter)
A parameter, component, or element that is relatively easily measured and that provides a broad amount of information about the state of an aquatic system; e.g., total dissolved solids (or conductivity); total suspended solids (or turbidity); pH; etc. (Delfino)

INDIGENOUS SPECIES
See SPECIES, INDIGENOUS

INDIRECT IMPACT
See IMPACT, INDIRECT

INDIVIDUAL SUSCEPTIBILITY
The variation in the degree to which individuals of the same species will respond to a given exposure to a toxic agent. (08)

INFORMATION
Conversion factors that link currency-flow subsystems. For example, the separated flows of carbon in the plant and animal biomass subsystem would be joined by information links that represent currency flows between the subsystems. (ECI)

INHERENT VARIATION
Inherent variation is the variation found in data when the outside factors that might influence these values are constant. The variation follows a consistent pattern. See OUTSIDE VARIATION. (ECI)

INTERMITTENT STREAM
See STREAM, INTERMITTENT

INTERRUPTED STREAM
See STREAM, INTERRUPTED

INTRODUCED SPECIES
See SPECIES, INTRODUCED

INVENTORY, SPECIES

A census of the flora and/or fauna inhabiting a defined area. The level of resolution of such a listing varies with the objectives of the study and may range from a listing of a few conspicuous or predominant species to a complete list for the area. A species inventory does not necessarily constitute an ecological baseline study and the two phrases should not be used interchangeably. (ECI)

INVERSION

A thermally stable atmospheric condition wherein surface air is prevented from rising by a layer of warmer air above. (00)

KEROGEN

A resinous hydrocarbon material that is the chief organic constituent of oil shale. When heated to 450 to 600°C, kerogen releases vapors that can be converted to raw shale oil, a black, viscous mixture of hydrocarbons. Shale oil can then be converted into petroleum products by refining. (08)

KEY SPECIES

See SPECIES, KEY

LATERAL MOVEMENT METHOD

See SURFACE MINING, LATERAL MOVEMENT METHOD

LEACHATE

Liquid that has percolated through a medium and has extracted dissolved or suspended materials from it. See LEACHING. (09)

LEACHING

Extraction of dissolved or suspended materials from a solid by a liquid. (Strickland)

LENTIC

Pertaining to standing (nonflowing) waters such as lakes, ponds, and swamps. See LOTIC. (26)

LETHAL DOSE 50

The dose of a toxic material that is lethal to 50% of the population of test organisms. The quality is commonly designated LD_{50}. (ECI)

LETHAL TOXICITY

See TOXICITY, LETHAL

LIFE FORM

A vegetation classification based upon the adaptations that plants have developed to allow them to survive in particular environments. (ECI)

LIGHT WATER REACTOR

The most prevalent type of nuclear reactor. Includes both boiling water reactors and pressurized water reactors. In both reactors, water is used as a coolant and as a moderator for the reaction process. See BREEDER REACTOR. (ECI)

LIMITING FACTOR
SEE FACTOR, LIMITING ENVIRONMENTAL

LINE SOURCE
In air pollution, a one-dimensional pollutant source such as a highway or haul road. See AREA SOURCE; POINT SOURCE. (ECI)

LITTER
The uppermost layer of organic debris on the ground under vegetation cover. It is composed primarily of freshly fallen or slightly decomposed vegetation material. (10)

LONG-TERM IMPACT
See IMPACT, LONG AND SHORT TERM

LONG-TERM SEEDING
See SEEDING, LONG-TERM

LOTIC
Pertaining to flowing waters such as streams and rivers. See LENTIC. (04; 26)

LOW-LEVEL POLLUTION
See POLLUTION, LOW-LEVEL

LOW WALL
The vertical wall, on the downslope side of a mining operation, consisting of the deposit being mined and some overlying rock and soil strata. (09)

MACROPHYTE
Any plant that can be seen with the naked, unaided eye; e.g., mosses, ferns, liverworts, rooted plants. (26)

MATHEMATICAL MODEL
See MODEL, MATHEMATICAL

MATRIX
1. A rectangular array of rows and columns of mathematical elements that can be combined to form sums and products. (13)

2. A figure resembling a mathematical matrix, such as a list of categories along vertical and horizontal axes with a designation of the interactions of any two components at the point of intersection. (ECI)

MATRIX, FLOW (Coupling Matrix)
A matrix that indicates the existence, magnitude, and direction of flows between the boxes of a box and arrow diagram. (ECI)

MEAN
The average value of all values under consideration. The most familiar is the arithmetic mean, or the sum of all the values divided by the number of values. (04; 05; 12)

MECHANISTIC MODEL

See MODEL, MECHANISTIC

MEDIAN

The value that separates an ordered set of values into halves. (04; 05; 12)

MEDIAN TOLERANCE LIMIT

See TOLERANCE LIMIT, MEDIAN

MESIC

Refers to environmental conditions that are intermediate in moisture supply. See HYDRIC; XERIC. (02)

MICROCLIMATE

1. A local climatic condition near the ground resulting from modification of relief, exposure, or cover. (09)

2. The fine climatic structure of the air space that extends from the very surface of the earth to a height where the effects of the immediate character of the underlying surface no longer can be distinguished from the general local climate (i.e., mesoclimate or macroclimate).

The microclimate varies with and is in turn superimposed upon the larger-scale conditions. While some rigid limits have been placed on the thickness of the layer concerned, it is more realistic to consider variable thicknesses - e.g., the microclimate of a putting green versus that of a redwood forest. Generally four times the height of surface growth or structures defines the level where microclimatic overtones disappear. (10)

MICROFLORA

A term used in general reference to four groups of microorganisms: bacteria, actinomycetes, fungi, and algae. (States)

MICROHABITAT (Microenvironment)

A small or restricted set of distinctive environmental conditions that constitute a small habitat, such as a tree stump, a dead animal, or a space between clumps of grass. (02; 09)

MEDIAN LETHAL DOSE (LD 50)

The dose of a toxin or pollutant that will kill 50 percent of a group of experimental animals. (08)

MIMICKING SYMPTOMS

Symptoms similar to those caused by pollutants, but induced by other abiotic or biotic causal agents. (00)

MINE DRAINAGE

Water forming on or discharging from a mining operation. (09)

MINE DRAINAGE, ACID

Acid water (pH less than 7) flowing on, or having drained or flowed from, any area of land affected by mining. (09)

MINE-MOUTH PLANT

A steam-electric plant or coal gasification plant built close to a coal mine; usually associated with delivery of output via transmission lines or pipelines over long distances, as contrasted with plants located nearer load centers and at some distance from sources of fuel supply. (08)

MINERALIZATION (Decomposition)

The release of inorganic ions by the oxidation of organic compounds; a process of nutrient release through microbial respiration (decomposition) of organic substrates. (States)

MITIGATION, IMPACT

Specific procedures to reduce or avoid potential impacts of development on the environment. (ECI)

MODE

The value that occurs most frequently in a set of values. (04; 05; 12)

MODEL

A representation or abstraction of a real system; an attempt to present some of the important features of the real system in a simplified way to aid understanding. Models may use words, pictures, or mathematics to present the abstractions. (ECI)

MODEL, DETERMINISTIC

A model in which the state of the system results from causes that can be determined, identified, and adequately described without considering probabilistic elements. As opposed to model, stochastic. (20)

MODEL, GRAPHICAL

The graphic portrayal of an idea, thought, or concept such as a trophic-level diagram of a functional ecosystem. (ECI)

MODEL, MATHEMATICAL

A model in which the components and the relationships between components of the real system are defined quantitatively and expressed in a series of equations. Observation of the effect of manipulation of variables in the equations allows one to make inferences about the behavior of the real system. (ECI)

MODEL, MECHANISTIC

A mechanistic model represents a biological system in terms of basic well-defined laws or relationships. A basic assumption of such a model is that the natural processes and, especially, life processes are mechanically determined and capable of complete explanation by the laws of physics and chemistry. (20)

MODEL, SIMULATION

A dynamic mathematical model that mimics the functioning of a system or process by the process of step-by-step solution of the equations that describe the system. (20)

MODEL, STOCHASTIC

A mathematical model whose variables acquire values drawn at random from some specified distribution. Stochastic models do not offer unique solutions, but rather provide a distribution of solutions with the probability of each corresponding to some specified probability distribution. As opposed to model, deterministic. (20)

MODERATE IMPACT

See IMPACT, MODERATE ECOLOGICAL

MODIFIED BLOCK CUT

See SURFACE MINING, MODIFIED BLOCK CUT METHOD

MONITORING PROGRAM, ENVIRONMENTAL

A program for measuring anticipated disturbances in environmental systems. The program often includes certain aspects of the baseline study program selected for their ability to detect alterations in local ecosystems caused by the project of interest. Monitoring programs are often subdivided into construction, operations, and postoperational stage monitoring programs. (ECI)

MOUNTAIN TOP REMOVAL

In this mining method, 100 percent of the overburden covering a coal seam is removed in order to recover 100 percent of the mineral. Excess spoil material is hauled to a nearby hollow to create a valley fill. (09)

MULTIPLE RANGE TEST

A method of comparing more than two mean values arising in analysis of variance by first ordering the means and then testing subsets of the means. (12)

MYCORRHIZAE

Literally "fungus-root." A mutually beneficial association between a fungus and the roots of plants. The fungi interact with root tissues in a way that increases the plants' ability to extract minerals from the soil. (03)

NATIVE SPECIES

See SPECIES, NATIVE

NATURAL DRAFT COOLING TOWER

See COOLING TOWER, NATURAL DRAFT

NECROSIS

Localized or general death of plant or animal tissue, often characterized by a brownish or black discoloration. (08)

NEKTON

Macroscopic organisms swimming actively in water; e.g., fishes. (04; 26)

NET PRIMARY PRODUCTIVITY

See PRODUCTIVITY, NET PRIMARY

NEUSTON
Microorganisms in contact with or in the surface film of a body of water. (06)

NICHE, ECOLOGICAL
A very controversial term. For our purposes, "niche" is considered to be the functional role of an organism within its community and ecosystem, resulting from the organism's structural adaptations, physiological responses, and specific behavior, (inherited and/or learned). The ecological niche of an organism depends not only on where an organism lives, but also on what it does. By analogy, it may be said that the habitat is the organism's "address," and the niche is its "profession." (10)

NONCONSERVATIVE POLLUTANT
See POLLUTANT, NONCONSERVATIVE

NONGAME SPECIES
See SPECIES, NONGAME

NONPOINT SOURCE
Any nonconfined area from which pollutants are discharged into a body of water, i.e., agricultural runoff, urban runoff, and sedimentation from construction sites. See POINT SOURCE; AREA SOURCE. (07)

NULL HYPOTHESIS
A statistical hypothesis of a form stating no difference exists between two parameters, between a parameter and a hypothesized value, or between an observed and a theoretical data distribution. (04; 05; 12)

OLIGOTROPHIC
Describing lentic waters, usually deep, with a low supply of nutrients and very little capability for supporting organic production. Dissolved oxygen is present at or near saturation throughout such lakes during all seasons of the year. See EUTROPHIC; DYSTROPHIC. (26)

ORIENTATION
Arrangement in any established position especially in relation to the points of the compass. (13)

OPEN PIT METHOD
See SURFACE MINING, OPEN PIT METHOD

OPERATION-STAGE MONITORING PROGRAM
See MONITORING PROGRAM, OPERATION-STAGE

ORPHAN BANK
Disturbed surfaces resulting from surface mines that were inadequately reclaimed or not treated at all, usually mined before the enactment of comprehensive reclamation laws. (ECI)

OUTSIDE VARIATION

Outside variation occurs in data when the values are being influenced by the action of a factor in the system. The variation does not follow a consistent pattern. See INHERENT VARIATION. (ECI)

OVERBURDEN

Material of any nature, consolidated or unconsolidated, that overlies a deposit of useful materials, ores, or coal, especially those deposits that are mined from the surface in open cuts. (ECI) (Hadley)

OVERSTORY

That portion of the trees in a forest, with more than one roughly horizontal layer of foliage, that forms the upper or uppermost layer. (10)

OVERTURN

See TURNOVER

OXIDANT

Any oxygen-containing substance that reacts chemically to oxidize other substances. Oxidants are the primary contributors to photochemical smog. (01)

OXYGEN DEMAND, BIOCHEMICAL (BOD; Biological Oxygen Demand)

A measure of the demand on a water body's dissolved oxygen supply that will be generated, over a specified time period, by the biological decomposition of organic material. A high BOD may temporarily or permanently so deplete the oxygen in water that aquatic life is killed. (10)

OXYGEN DEMAND, CHEMICAL (COD)

A measure of the amount of a water body's dissolved oxygen supply that would be used up in completely oxidizing added inorganic oxidizable compounds - such as in the oxidation of ammonia to nitrate.

Biological oxygen demand (BOD) tests can measure only the biodegradable fraction of the total potential dissolved oxygen consumption by added wastes; however, COD tests may be used to measure the oxygen demand created by toxic organic or inorganic compounds as well as by biodegradable substances. A standard COD test, therefore, can be used to evaluate many industrial wastes not readily analyzed for water quality factors by the sewage-oriented BOD test. See OXYGEN DEMAND, BIOCHEMICAL. (13)

OZONE

A form of oxygen (O_3) produced by reactions in photochemical smog and in electrical discharges. It is a powerful oxidizing agent that is toxic to both plants and animals at relatively low concentrations. (08)

PAN

Peroxyacetyl nitrate, a pollutant created by the action of sunlight on hydrocarbons and nitrogen oxides in the air. PANs are an integral part of photochemical smog. (01)

PARAMETER

1. A quantity that characterizes or describes a statistical population (e.g., a population mean); it is estimated by a sample statistic. (04; 12; 13)

2. In systems ecology, a quantified estimate or measurement of the value of an attribute of a component of an ecological system; e.g., the parameter gm/m^2 provides a measure of biomass (attribute) for some species or group of species of organisms for a given site. (ECI)

PARAMETER, CHEMICAL
See INDICATOR, CHEMICAL

PARTICULATE MATTER
Solid particles such as ash, that are released in exhaust gases from the combustion process at fossil-fuel plants. (08)

PERCOLATION
Downward movement of water through soils or parent materials. (09)

PERENNIAL STREAM
See STREAM, PERENNIAL

PERIPHYTON
A community of aquatic organisms (usually small but densely set) closely attached to stems and leaves of rooted aquatic plants or other surfaces projecting above the bottom. (04; 06)

PERMEABILITY
The measure of the ability of a substance or material to allow a fluid to pass through it. (Strickland)

PERMEABILITY, COEFFICIENT OF
The rate of flow of a fluid through a unit cross section of a porous mass under a unit hydraulic gradient, at a temperature of 60° Fahrenheit. (09)

PERTURBATION, ENVIRONMENTAL
A disturbance that occurs in an environmental system resulting in a measurable change in components or processes of that system. (ECI)

PHENOLOGY
The study of the periodic phenomena of animal and plant life and their relations to weather and climate, e.g., the annual time of flowering in plants. (02)

PHOTOCHEMICAL OXIDANTS
Secondary pollutants formed by the action of sunlight on nitrogen oxides and hydrocarbons in the air; they are the primary constituents of photochemical smog. (08)

PHOTOCHEMICAL SMOG
See SMOG, PHOTOCHEMICAL

PHOTOPERIOD
The duration of light during a 24-hour period. (02)

PHREATOPHYTE
A desert plant with a tap root capable of reaching the water table. (27)

PHYTOPLANKTON
The plant (algal) portion of plankton. See PLANKTON; ZOOPLANKTON. (ECI)

PIT
Used in reference to a specifically describable area of open-cut mining. May be used to refer either to only that part of the open-cut mining area from which coal is being actively removed or to the entire contiguous mined area. (09)

PLANKTON
Aquatic plants and animals, mostly microscopic, that drift with water currents. (Zar)

PLANT MONITORS
Plant biological indicators maintained to obtain or approximate a measure of the concentration of pollutants. (00)

PLANT SPECIES, DECREASER
Range management usage: Plant species of the original vegetation that will decrease in relative amount in population density or cover with continued grazing or overuse. (02; 10)

PLANT SPECIES, INCREASER
Range management usage: Plant species of the original vegetation that increase in relative abundance in population density or cover, at least for a time, because of overuse. (10; Zar)

PLUME
The path taken by the continuous emission from a stack or aquatic discharge. (00)

POINT SOURCE
A stationary emitting point of a pollutant, e.g., a stack or a discharge pipe; in contrast to an area source or a nonpoint source. See AREA SOURCE; LINE SOURCE. (00)

POLLUTANT
Any contaminant that, when present in the air or water, detracts from or interferes with the desired use or natural state of that air or water. (08)

POLLUTANT, CONSERVATIVE
A pollutant that is relatively persistent and resistant to degradation, such as PCB and most chlorinated hydrocarbon insecticides. (Beeton)

POLLUTANT, NONCONSERVATIVE
A pollutant that is quickly degraded and lacks persistence, such as most organoposphate insecticides. (Beeton)

POLLUTION

An undesirable change in the physical, chemical, or biological characteristics of air, land, and water that may or will harmfully affect human, plant, or animal life, industrial processes, living conditions, or cultural assets; or that may or will waste or deteriorate raw material resources. See POLLUTANT. (03)

POLLUTION, HIGH LEVEL

Pollution levels above those ordinarily recorded by urban or industrial monitoring. (Eversman)

POLLUTION, LOW LEVEL

Pollution levels that approach average levels of pollutants actually monitored in urban or industrial areas. (Eversman)

POPULATION, BIOLOGICAL

An assemblage of individuals of the same species inhabiting a given area at a given time. (04)

POPULATION DENSITY

See DENSITY

POPULATION DYNAMICS

Changes in population size and structure. (Zar)

POPULATION, ENDEMIC (Native Population)

An assemblage of individuals of the same species or subspecies restricted to a limited geographic area or habitat type. (ECI)

POPULATION PRESSURE

The combined effects exerted by the individuals of a population upon each other, upon the other organisms in a community, and upon their physical environment. (02; Zar)

POPULATION, STATISTICAL

In a statistical sense, a population refers to the complete set of data that is under study. (05)

PRECIPITATOR

See ELECTROSTATIC PRECIPITATOR

POROSITY

The porosity of a rock or soil is the property of containing interstices or voids and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume. It may be expressed as a decimal fraction or as a percentage. (11)

POROSITY, EFFECTIVE

Refers to the amount of interconnected pore space available for fluid transmission. Expressed as a percentage of the total volume occupied by the interconnecting interstices. (11)

POWER, STATISTICAL
Statistical power refers to the probability that a statistical test rejects the null hypothesis when it is false. (18)

PRECIPITATOR
See ELECTROSTATIC PRECIPITATOR

PRECISION
Precision, in the general statistical sense, denotes the uniformity or similarity of repeated observations to each other, without regard to their accuracy in estimating a true value. (04; 05; 12)

PRIMARY SUCCESSION
See SUCCESSION, PRIMARY

PROBABILITY
The relative frequency with which a given event will occur out of a total number of possible events. Generally expressed as a percentage or a ratio. (ECI)

PROBABILITY DISTRIBUTION
See DISTRIBUTION, PROBABILITY

PROCESS
In an ecosystem, a process is a functional activity that regulates a flow of matter or energy between two components of the system; (e.g., photosynthesis is one of the processes regulating the flow of carbon between the atmosphere and plants. See COMPONENT; ATTRIBUTE; PARAMETER.

PRODUCER
An organism that can synthesize organic material by combining inorganic materials and an external energy source (light or chemical). The most common producers are green plants, which employ photosynthesis. See CONSUMER; DECOMPOSER; TROPHIC LEVEL. (06; Zar)

PRODUCTION
1. The amount of organic material produced by biological activity in a given area or volume. (04; 06)

2. The total amount of energy stored over a specified period by an organism or organisms. (03; 04)

PRODUCTIVITY
1. The rate of production of organic matter produced by biological activity in an area or volume (e.g., grams per square meter per day). See PRODUCTIVITY, NET PRIMARY. (03; 04)

2. The innate capacity of an environment to produce plant and animal life. (02)

3. The capacity of a soil to produce a certain kind of crop under a defined set of management conditions. (02)

4. The rate of storage of organic matter or energy in tissue by organisms, including the matter or energy used by the organisms in maintaining themselves. See PRODUCTIVITY, GROSS PRIMARY. (Beeton)

PRODUCTIVITY, GROSS PRIMARY
The rate of synthesis of organic material or energy fixation by photosynthesis (or chemosynthesis), including that which is used up in respiration by the producer organism. (06)

PRODUCTIVITY, NET PRIMARY
The rate of accumulation of organic material or energy in producer tissues. Net primary productivity equals gross primary productivity minus the rate of respiratory utilization by the producer organism. (04; 06)

PRODUCTIVITY, SECONDARY
The rate of new biomass addition (weight and growth) or energy storage by herbivorous consumer organisms. (Zar)

PRODUCTIVITY, TERTIARY
The rate of new biomass addition (weight and growth) or energy storage by meat eating (i.e., carnivorous) animals. (10)

RADWASTES
A commonly used abbreviation for radioactive wastes, liquid, gaseous, and solid, produced by nuclear power plants. (ECI)

RANDOM SAMPLE
See SAMPLE, RANDOM

RANGE CONDITION AND TREND
1. Range condition: The status of selected vegetation and soil characteristics of a given range area in relation to the optimum status of these characteristics (considered by some to be the climax community) obtainable under the prevailing environmental conditions. (02)

2. The terms range condition and trend are used to express the idea that at any given time a vegetation unit assumes a specific set of characteristics (condition) and that these characteristics change (trend). (28)

RANGE, STATISTICAL
In statistical usage, the range is the largest value of a set of values minus the smallest value. (04; 05; 12)

RARE SPECIES
See SPECIES, RARE

RATE PROCESS VARIABLE
See VARIABLE, RATE PROCESS

REACTOR, BREEDER
See BREEDER REACTOR

REACTOR, LIGHT WATER
See LIGHT WATER REACTOR

RECLAMATION (Rehabilitation)
1. The process of reconverting mined or other disturbed land to its former or other productive uses. (09)

2. The process of making a site habitable to organisms that were originally present or others that approximate the original inhabitants. (ECI)

See RESTORATION.

REFORESTATION
The natural or artificial restocking of an area with forest trees. See AFFORESTATION. (09)

REFUSE
All solid waste from a coal mine, including tailings and slurry. Other synonyms are: dirt, gob, shale, slate, etc. (09)

REGRESSION
1. Simple: A statistical analysis procedure in which an algebraic relationship (a simple regression equation) is derived that describes how the magnitude of a variable (the dependent variable) changes with the magnitude of a second variable (the independent variable) and determines whether the relationship is statistically significant. (12)

2. Multiple: A statistical analysis procedure in which an algebraic relationship (a multiple regression equation) is derived that describes how the magnitude of a variable (the dependent variable) changes with the magnitudes of two or more variables (independent variables) and determines whether each of the independent variables has a statistically significant effect on the dependent variable. (12)

RELATIVE ABUNDANCE
See ABUNDANCE, RELATIVE

RELATIVE DENSITY
See DENSITY, RELATIVE

REPRESENTATIVE SPECIES
See SPECIES, REPRESENTATIVE

RESOLUTION
The relative ability to detect impacts in an aggregation of similar biotic components. Resolution generally increases as aggregation decreases. (ECI)

RESPIRATION
The process of extracting energy from organic material by catabolic (breakdown) metabolism. (Zar)

RESPONSE
See IMPACT; IMPACT, ECOLOGICAL

RESTORATION
The process of restoring site conditions to the way they were before occurrence of land disturbance. See RECLAMATION; REHABILITATION. (09)

ROUGH FISH
See FISH, ROUGH

RUNOFF
The portion of rainfall that is not absorbed into the ground. It is utilized by vegetation or lost by evaporation or may find its way into streams as surface flow. (09; Strickland)

RUN-OF-MINE
Coal in various shapes and sizes as it comes from the mine. (08)

SAMPLE
The part of a population that is collected or measured, usually through a deliberate selection procedure, for the purpose of drawing conclusions about the properties of the parent population. (05)

SAMPLE, RANDOM
A sample collected in such a way that each member of the population has an equal and independent probability of being selected. (ECI)

SAMPLE SIZE
The number of sampling units are to be included in a sample. (05)

SCRUBBER
A device used to remove solid, liquid, or gaseous pollutants from a gas stream by passing the gas through a moist filter or a liquid spray. (00)

SEASONALITY
The influence that the time of the year has on the components and processes of an ecosystem. Also, the influence of the time of the year on the data that are acquired for the components and processes in an ecosystem. (ECI)

SECONDARY PRODUCTIVITY
See PRODUCTIVITY, SECONDARY

SECONDARY SUCCESSION
See SUCCESSION, SECONDARY

SEDIMENT
Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice, and has come to rest on the earth's surface. (09)

SEDIMENT TRAP (Sediment Basin)
A small temporary basin formed by an excavation and/or embankment to intercept sediment-laden runoff and to trap and retain the sediment. In

so doing, drainageways, properties, and rights-of-way below the trap are protected from sedimentation. (17)

SEEDING, LONG-TERM
The replanting of vegetation for the long-term or permanent stabilization of spoils and overburden storage piles and to create wildlife habitat. See SEEDING, TEMPORARY. (ECI)

SEEDING, TEMPORARY
The replanting of vegetation for the temporary stabilization of spoil piles, overburden storage piles, etc. until permanent revegetation is completed. See SEEDING, LONG-TERM. (ECI)

SENSITIVITY
A physiological condition of susceptible organisms or tissues whereby they are prone to injury by pollutants. (00)

SERAL STAGES
Developmental temporary communities in a sere. (04;06)

SERE
A developmental series of communities, each replacing the previous one during ecological succession. The initial, or pioneer, stage is followed by one or more transitional stages, that ultimately terminate in a climax stage. Each stage up to the climax creates conditions that eventually become more favorable to the next stage than to itself. See COMMUNITY, CLIMAX. (04)

SHORT-TERM IMPACT
See IMPACT, LONG AND SHORT TERM

SHOCK LOADING
High and low surges of input contaminants to biological oxidation units capable of causing upsets. (08)

SIGNIFICANCE LEVEL
In testing a statistical hypothesis, the significance level is the probability that the null hypothesis is true. (04;12)

SIGNIFICANCE, STATISTICAL
An effect is said to be significant if the null hypothesis is rejected; that is, that the observed effect is of such magnitude that it is unlikely to have occurred by chance. (04)

SIGNIFICANT IMPACT
See IMPACT, SIGNIFICANT

SIGNIFICANT SPECIES
See SPECIES, SIGNIFICANT

SILT
Finely divided particles of soil or rock that are often carried in cloudy suspension in water and eventually deposited as sediment. (08)

SIMULATION

The imitative representation of the function of one system or process by examination of the function of another. Essentially, simulation consists of a representation of a system or organization by means of a model. The behavior of the system under various possible conditions is then analyzed through repeated manipulation of the model. See MODEL, SIMULATION. (10; 20)

SIMULATION MODEL

See MODEL, SIMULATION

SINK

An infinite receptacle outside the system of interest for flows of matter or energy. (ECI)

SLIP (Slide)

A mass of spoil material that moves downward and outward to a lower elevation due to the force of gravity, generally caused by overloading of the downslope, freezing and thawing, or saturation of the fill. (09)

SLOPE (Grade)

The inclination of a stream channel or ground surface, usually expressed in terms of the ratio or percentage of number of units of vertical rise or fall per unit of horizontal distance. The slope of a terrestrial surface is an important factor in erosion potential. It interacts with aspect to influence basic rates of evapotranspiration. (09)

SLOPE STABILITY

The resistance of any inclined surface, such as the wall of an open pit or cut, to slide or collapse. (09)

SLURRY

1. Refuse, of relatively small size, that is separated from the coal in the coal cleaning process and is readily pumpable in the washing-plant effluent. (ECI)

2. A pulverized coal-liquid mixture transported by pipeline. (09)

SMOG

1. In general, term broadly used to mean polluted air. (08)

2. In a specific sense, a mixture of smoke and fog. (ECI)

SMOG, PHOTOCHEMICAL

An eye-irritating atmospheric condition resulting from a very complex series of chemical reactions involving reactive organic substances and nitrogen oxides and initiated by ultraviolet light from the sun. See PHOTOCHEMICAL OXIDANTS. (08)

SMOKE

Solid and/or liquid gas-borne particles, often less than 1 micron in diameter, formed by incomplete combustion of carbonaceous materials and present in sufficient quantity to be visible. (00)

SOCIABILITY
The tendency of organisms to aggregate as individuals or as groups within a community. (04)

SOCIAL DOMINANCE
See DOMINANCE, SOCIAL

SOIL
The surface layer of the earth ranging in thickness from a few inches to several feet. It is composed of finely divided rock debris mixed with decomposing vegetative and animal matter and is capable of supporting plant growth. (09)

SOIL HORIZON
A term applied to a layer of soil that differs in composition or structure, or both, from adjacent layers. The various horizons in a soil are generally described by a diagram representing a vertical section of the soil called a soil profile. (04; 10)

SOIL PROFILE
1. The physical and chemical features of the soil imagined or seen in vertical section from its surface to the point at which the characteristics of the parent rock are not modified by surface weathering or soil processes. (06)

2. A vertical series of soil horizons. (04)

SORPTION
1. A process by which one substance takes up and holds the molecules of another substance, as by absorption or adsorption. (ECI)

2. The process of uptake and retention of gases by plants. (00)

SOURCE
In systems ecology, an infinite supply outside the system of interest for flows of matter or energy. (ECI)

SPECIES ABUNDANCE
See ABUNDANCE, SPECIES

SPECIES, BIOLOGICAL
A unit of classification of organisms, consisting of those individuals actually or potentially sharing a common gene pool. (Zar)

SPECIES, CHEMICAL
A term used to describe the physical form or chemical oxidation state of a chemical element. (Delfino)

SPECIES COMPOSITION
The kinds and numbers of species jointly occupying a specified area. (06)

SPECIES DIVERSITY INDEX
See DIVERSITY, INDEX OF SPECIES

SPECIES, DOMINANT
See DOMINANCE

SPECIES, ENDANGERED

1. An endangered species, or subspecies, of animal or plant is one whose prospects of survival and reproduction are in immediate jeopardy.

Its peril may result from one or many causes: loss of habitat or change in habitat, overexploitation, predation, competition, disease or even unknown reasons. To survive, an endangered species must receive the assistance of man through habitat preservation and development and legislated protection. (10)

2. Those species in danger of extinction throughout all or a significant portion of their ranges. Species or subspecies from very limited areas or from restricted, fragile habitats usually are considered "endangered." (10)

3. Many states also have their own lists of endangered species. California, for example, designates a species or sub-species as endangered if any of the following conditions are true for the species under consideration: a) the mortality rate consistently exceeds the birth rate; b) it is incapable of adapting to environmental change; c) its habitat is threatened by destruction or serious disturbance; d) its survival is threatened by predation, competition, or disease; e) environmental pollution threatens its survival. See SPECIES, RARE; SPECIES, THREATENED. (10)

SPECIES FREQUENCY
See FREQUENCY, SPECIES

SPECIES, GAME

1. Wild animals, usually mammals, fishes, or birds, hunted for sport or food and subject to legal regulations. (06)

2. U.S. Forest Service usage: any species of wildlife for which seasons and bag limits have been prescribed, and which are normally restricted to possession by sportspersons under state laws and regulations. (10)

SPECIES, IMPORTANT
See SPECIES, SIGNIFICANT

SPECIES, INDICATOR
See INDICATOR, BIOLOGICAL

SPECIES, INDIGENOUS (Native Species)

Any species of plant or animal native to a given land or water area.

For planning purposes, indigenous species will include introduced or exotic species that have established a niche in the area's ecosystem and are compatible with management objectives. Hungarian and chukar partridges are examples. (10)

SPECIES, INTRODUCED (Exotic Species)

Any species that is not native in the area where it occurs. (10)

SPECIES INVENTORY
See INVENTORY, SPECIES

SPECIES, KEY
A species that plays an important ecological role in determining the overall structure and dynamic relationships within a biotic community.

A component species of a biotic community whose presence is essential to the integrity and stability of a particular ecosystem.

Key species may be unimportant as energy transformers in a biotic community (i.e., they may be neither very abundant nor consume large portions of the biotic productivity or a community). However, slight variations in key-species' abundance results in large changes in the abundance of other species and/or in biotic-community relationships and structure. (10)

SPECIES NATIVE
See SPECIES, INDIGENOUS

SPECIES, RARE
1. Species occurring as a very few individuals or small groups at widely scattered localities over a large geographic area of what appears to be suitable habitat. (10)

2. Species found in very small numbers widely dispersed in each community where they grow, but which occur in many suitable areas over their geographic range. (10)

3. Species with a range restricted to so few localities that they are considered rare even though they occur in large numbers at each locality. (10))

4. Animals are declared "rare" by the California Fish and Game Commission because their continued existence is threatened by one or more conditions. If any of the following conditions are true, the species (or sub-species) under consideration is declared rare: a) it is confined to a relatively small and specialized habitat, and it is incapable of adapting to different environmental conditions; b) although found in other parts of the world, it is nowhere abundant; c) it is so limited that any appreciable reduction in range, numbers, or habitat would cause it to become endangered; or d) if current management and protection programs were diminished in any degree, it would become endangered. Other states also designate certain species as "rare," according to various criteria. The federal government uses the term "threatened" rather than "rare" in the same context. See SPECIES, THREATENED; SPECIES, ENDANGERED. (10)

SPECIES, REPRESENTATIVE
Species characteristic of certain communities of plants or animals. (Zar)

SPECIES RICHNESS
The number of species in a given area. (04)

SPECIES, SIGNIFICANT (Important Species)

Species considered valuable for the niche they occupy in an ecosystem; for their status as rare, threatened, or endangered; or for their rank on the human social scale of value judgments concerning sport, aesthetics, etc. (ECI)

SPECIES, SUB

A taxon of distinct, geographically separated complexes of genes, a category immediately below "species" and above "variety" (if varieties are recognized in a species), sometimes considered synonymous with variety, or as an incipient species. (02)

SPECIES, THREATENED

Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range and which has been designated in the Federal Register by the Secretary of the Interior as a threatened species.

This includes species categorized as rare, very rare, or depleted. Many states also have lists of threatened species which may be more encompassing, for various reasons, than the Federal lists. See SPECIES, RARE; SPECIES, ENDANGERED. (10; Heggen)

SPOIL

The overburden or material other than coal (or other mineral) removed in gaining access to the coal (or other mineral) in surface mining. (Zar)

SPOIL, ACID

Usually spoil material containing sufficient pyrite so that weathering produces acid water and the pH of the soil determined by standard methods of soil analysis is between 1.0 and 6.9. (09)

SPOIL BANK

A mound of mine refuse created by the deposit of overburden or noncoal material prior to backfilling the coal seam. Synonyms include cast overburden, tip, culm, gob, refuse pile, slate dump, stack, and heap. (09)

SPOIL, TOXIC

Includes acid spoil with pH below 4.0. Also refers to spoil having amounts of minerals such as aluminum, manganese, and iron that adversely affect plant growth. (09)

SPRAY CANAL

A heat dissipation system used in electric power generation. Heated water is sprayed into the air where some of it evaporates, thereby cooling the rest. Sprayed water is collected in canals that recirculate the water, repeating the process until the water is cool enough for discharge.

SPRING OVERTURN

See OVERTURN, SPRING

STABILITY

See ECOSYSTEM STABILITY

STACK

A smokestack; a vertical pipe or flue designed to vent gases and suspended particulate matter into the surrounding air. (01)

STACK GAS

See FLUE GAS

STAGNATION

A condition in some lakes in summer and winter when thermal stratification prevents water circulation to the bottom waters (hypolimnion) and oxygen depletion occurs there. See HYPOLIMNION; STRATIFICATION, THERMAL. (Zar)

STANDARD DEVIATION

A measure of the dispersion of a set of values about their mean, equal to the positive square root of the variance. (04; 05; 12)

STANDARD ERROR

A measure of the dispersion of a set of estimates about the parameter they estimate. The term is used most frequently to imply the standard error of the mean, or the dispersion of the estimates of the mean about the true mean. It is a statistic that is important in establishing confidence intervals for the population mean. (04; 05; 12)

STAND DENSITY

See DENSITY, STAND

STANDING CROP

The total number or the total biomass of one or more species in an area at a given time. An instantaneous measure of numbers or biomass. (Zar)

STATE VARIABLE

See VARIABLE, STATE

STATISTIC

A summary value calculated from sampling data that estimates a population parameter (A characteristic of the population from which the sample was obtained). (21, 33, 34)

STATISTICS (Statistical Analysis)

The analysis and interpretation of data with the purpose of objectively evaluating the reliability of the conclusions based on the data. Statistical methods allow us to (1) quantitatively describe and summarize characteristics of sets of data, (2) draw conclusions about large populations from small portions (samples) of them, and (3) objectively assess differences and relationships between sets of data. (04; 12)

STATISTICAL SIGNIFICANCE

See SIGNIFICANCE, STATISTICAL

STOCHASTIC MODEL

See MODEL, STOCHASTIC

STRATIFICATION, CHEMICAL

1. A condition found in temperate lakes during the summer and winter stagnation periods in which certain horizontal strata become chemically different from adjacent ones, often with abrupt transitions between them. (02)

2. A layering of water in a lake due to density differences caused by variations in the concentrations of dissolved substances at different depths. (26)

STRATIFICATION, THERMAL

The layering that occurs within a water mass due to temperature and concomitant density changes with depth. The successive horizontal layers have different temperatures and each layer is sharply differentiated from the adjacent ones. See OVERTURN; STAGNATION. (26)

STRATIFICATION, VEGETATIVE

The occurrence of vegetation in more or less distinct horizontal layers, or strata; e.g., ground, herb, shrub, and tree strata. (Zar)

STREAM, INTERMITTENT (Temporary Stream)

A stream that flows only part of the year.

STREAM, INTERRUPTED (Discontinuous Stream)

A stream in which part of the flow is underground.

STREAM, PERENNIAL (Permanent streams)

A stream that flows throughout the year with water covering the substratum over its entire course. (Zar)

STRESS

1. The conditions resulting from any environmental change or perturbation that disturbs the normal functioning of an organism to such an extent that its chances for survival or reproduction are reduced. (26)

2. The result or consequent state of a physical or chemical or social stimulus on an organism or system; properly, a state of strain resulting from stress. (06)

3. Systemic: The condition of an organism in which large parts of the body deviate from the normal resting state, either because of activity of the body part or because of an injury. (02)

STRESS, THERMAL

1. Engineering context: Measure of heat levels applied to boilers, condensers, etc. (ECI)

2. Biological context: A condition of impaired functioning of an organism or population of organisms resulting from unusual temperatures in the surrounding medium. (ECI)

STRESS, WATER

The total energy by which water is held in the soil. (02)

STRIP MINING

See SURFACE MINING, STRIP

SUBSIDENCE

1. A downward movement of the ground surface caused by dissolution and collapse of underlying soluble deposits, rearrangement of particles upon removal of underground mineral deposits, or reduction of fluid pressures within an aquifer or petroleum reservoir. (10)

2. The sinking of a substance to a lower level, e.g., the transport of ozone from the stratosphere to the atmosphere by air turbulence. (00)

SUBSPECIES

See SPECIES, SUB-

SUBSTRATUM

This is the correct term for the surface on or in which organisms live. (Light)

SUCCESSION, ECOLOGICAL

An orderly process of biotic community development that involves changes in the presence of species and communities over time; it is reasonably directional and, therefore, reasonably predictable.

It results from modification of the physical environment by the community; that is, "succession" is community-controlled even though the physical environment determines the pattern and the rate of change, and often sets limits as to how far development can go.

It may culminate in a stabilized ecosystem in which maximum biomass is maintained per unit of available energy flow.

The whole sequence of communities that replace one another in a given area is called the sere; the relatively transitory communities are variously called "seral stages" or "developmental stages" the earliest of which is termed the "pioneer stage," while the terminal stabilized system is known as the "climax".

Species replacement in the sere occurs because populations tend to modify the physical environment, creating conditions favorable for other populations until a community is established that is selfperpetuating in the existing abiotic environment. (10)

SUCCESSION, PRIMARY

Succession that begins on fresh, recently exposed substratum that has not previously supported vegetation. (04; 06)

SUCCESSION, SECONDARY

Succession that occurs on formerly vegetated areas (i.e., areas that have a developed soil) after a disturbance such as clearing, fire, mining, or agriculture. It generally occurs at a more rapid pace than primary succession due to the organic material and nutrients that are already present. (04)

SURFACE MINING

A mining method whereby the overlying materials are removed to expose the mineral for extraction. (05)

SURFACE MINING, BLOCKCUT METHOD

A method of surface mining in which overburden is removed and placed around the periphery of a box-shaped cut. After coal is removed the spoil is pushed back into the cut and the surface is blended into the topography. (05)

SURFACE MINING, EXTENDEDBENCH METHOD

A method of surface mining in deep overburden that employs a large-capacity walking dragline operating from a machine supporting bench that is formed by filling the pit between the partially stripped highwall and the last cut spoil bank. (09)

SURFACE MINING, LATERALMOVEMENT METHOD

A method of surface mining in which coal is removed by stripping and augering with no material being placed on the downslope. Lateral movement reduces disturbed acreage by nearly two-thirds when compared with conventional surface mining because the overburden is hauled by truck laterally along the bench and then backfilled against the highwall. (09)

SURFACE MINING, MODIFIEDBLOCKCUT METHOD

This method of surface mining adapts the block cut method to steeply sloped areas. The modification essentially is backfilling with spoil from succeeding blocks rather than from the spoil-producing block. (09)

SURFACE MINING, OPENPIT METHOD

A type of surface mining in which the overburden is removed from the product being mined and is dumped back after mining; or an area from which the overburden has been removed and not replaced. (09)

SURFACE MINING, STRIP

Surface mining in which the overburden is removed in narrow strips and placed in adjacent pits producing an uneven surface of ridges resembling a plowed field. (Hadley)

SUSPENDED SOLIDS (S.S.)

Small particles of solid pollutants that resist separation by conventional means. S.S. (along with BOD) is used as a measurement of water quality and an indicator of waste-treatment-plant efficiency. (07)

SYNERGISTIC EFFECTS

Effects that together form impacts "greater than the sum of their parts, " e.g., timber-harvesting practices may increase water temperatures, which make fish more susceptible to disease, while also decreasing the dissolved oxygen content of the water, creating conditions of severe stress for fish. See EMERGENT PROPERTIES. (25)

SYSTEMS ANALYSIS

The study of how component parts of a system interact and contribute to the functioning of the total system.

SYSTEMS APPROACH

A systematic consideration of problems wherein analysis and intuition are both emphasized. A systems approach implies the seeking of an optimal course of action. It entails: a) compiling, condensing, and synthesizing a great amount of information concerning the components of the system and their functions, b) examining in detail the structure of the system, c) translating this knowledge of system components, function, and structure into models of the system, and d) using the models to derive new insights about management and utilization of the systems in question. (20)

SYSTEMS ECOLOGY

See ECOLOGY, SYSTEMS

SYSTEMS MODEL

See MODEL, SYSTEMS

t-STATISTIC

In general usage, it is any statistic that follows Student's t distribution. Its most familiar occurrences are in testing statistical hypotheses concerning differences between two means, between one mean and a hypothesized value, or in setting confidence intervals for a population mean. (ECI)

TAILINGS

Mineral refuse, such as from a milling operation, that is usually deposited out of a water medium. (09)

TAXON

A unit or category of systematic classification, e.g., variety, species, genus, family, class. (ECI)

TEMPORARY SEEDING

See SEEDING, TEMPORARY

TERRACE

Sloping ground cut into a succession of benches and steep inclines between benches for purposes of revegetation or to control surface runoff and minimize soil erosion. (09)

TERRACE, ABSORPTIVE

A type of terrace that is designed primarily for moisture collection and retention. (09)

TERRACE, BENCH

A terrace that has a steep or vertical drop to the slope below and a horizontal or gentle sloping surface. They are most commonly used on steep slopes. (09)

TERRACE, DRAINAGE

A broad channel-type terrace used primarily to conduct water from the area at a low velocity. It is adapted to less absorptive soil and high rainfall. (09)

TERTIARY PRODUCTIVITY
See PRODUCTIVITY, TERTIARY

THERMAL DISCHARGE
See DISCHARGE, THERMAL

THERMAL STRATIFICATION
See STRATIFICATION, THERMAL

THERMAL STRESS
See STRESS, THERMAL

THERMOCLINE
The shallow layer of water lying between the epilimnion and hypolimnion in a lake. The temperature of the thermocline exhibits the abrupt transition between the two layers.

THREATENED SPECIES
See SPECIES, THREATENED

THRESHOLD SENSITIVITY LEVEL
The minimum level of exposure to a specific pollutant that results in a detectable effect. It is important to note that threshold levels are defined relative to the applied technology's ability to detect an effect. (Mellinger; Bromeshenk)

THRESHOLD TOXICITY
See TOXICITY, THRESHOLD

TILTH
The physical condition of a soil in respect to its fitness for the growth of a specified plant. (09)

TIME HORIZON
The calendar date at which a project is to be completed. It may be accompanied by a well defined schedule of performance or product milestones to be attained in the course of the project. (ECI)

TOLERANCE, ECOLOGICAL
1. The resistance of an organism to the excess or to the deficiency of an element or a condition in its environment. (10)

2. The capacity of an organism to endure or adapt to (usually temporary) stress. (06)

3. An organism's capability to withstand a condition indefinitely and through all life stages. (ECI)

See AMPLITUDE, ECOLOGICAL.

TOLERANCE LIMIT, MEDIAN
The concentration of some toxic substance at which 50% of the test organisms are able to survive for a specified period of exposure. See LETHAL DOSE 50. (10)

TOPSOIL

Presumed fertile soil material. Distinction has been made among synthetic, weathered, and geologic topsoil. Synthetic topsoil can include sand and stone chips as well as fly ash, sawdust, or manure not usually a part of geological soil and rock. Weathered topsoil is the natural surface material that has been subjected to weathering throughout geologic time. See SOIL. (09)

TOXIC

Possessing the quality of being able to produce deleterious effects on the physiological processes of an organism. (ECI)

TOXICANT

A substance that kills or injures living organisms by its chemical or physical actions, or by altering the environment of the organism. (00)

TOXICITY

The quality, state, or relative degree of being toxic or poisonous; the ability of a chemical molecule or compound to produce injury when it reaches a susceptible site in the body. (08)

TOXICITY, ACUTE

1. Any poisonous effect produced within a short period of time, usually within 24 to 96 hours, that results in severe biological harm or death. (08)

2. Inhibition of some organismal function after brief exposure or low concentration exposure to a toxicant. (Berry)

TOXICITY, CHRONIC

Inhibition of an organismal function that may be lethal or sublethal after a long-term (relative to life cycle) exposure to a toxicant. (Berry)

TOXICITY, LETHAL

Concentration at which a poison or toxin causes death of an organism. See LETHAL DOSE 50. (Berry)

TOXICITY, THRESHOLD

1. Concentration at which a toxicant first causes inhibition. (Berry)

2. The lowest concentration (of a toxicant) that causes acute toxicity. (ECI)

TOXICITY, UNIT

Inhibition per log unit of toxicant at concentrations greater than threshold toxicity. (Berry)

TOXIC SPOIL

See SPOIL, TOXIC

TOXIC WASTES

Wastes that contain chemical substances in sufficient quantity to produce deleterious effects on organisms. (ECI)

TOXIN

A poison of organic origin. (27)

TRACE ELEMENTS

Chemical elements usually appearing in minute quantities in natural systems or media; the micas that may occasionally be concentrated by specific organisms. Nutrients such as phosphorus, even when in minute quantities, are not usually called trace elements. See ESSENTIAL ELEMENT. (06)

TRANSECT

A sampling technique in which lines or belts are systematically laid out across a specific geographical area. The lines or belts are then traversed and quantitative data collected from the biological components of interest along them. (ECI)

TURNOVER (Overturn)

Circulation of the entire water column of a lake after the disappearance of thermal stratification. It may occur in the autumn after summer stratification or in the spring after winter stratification. (Zar)

TRANSPIRATION

The loss of water vapor from a plant, mostly through the stomata of the leaves and the lenticels of stems and twigs. (02)

TROPHIC LEVEL

A link in a food chain. One of the parts of a nutritive series in an ecosystem in which a group of organisms in a certain stage in the food chain secures food in the same general manner. The first or lowest trophic level consists of producers (usually green plants); the second level, of herbivores (primary consumers); and the third level, of primary carnivores (secondary consumers). Bacteria and fungi are organisms in the decomposer trophic level. (02)

UNDERSTORY

The trees and other woody species growing under a more or less continuous cover of branches and foliage formed collectively by the upper portions of adjacent trees and other woody growth of the overstory. (10)

UNIT TOXICITY

See TOXICITY, UNIT

VARIABLE

Any characteristic that varies or takes on any of a specified set of values. (04; 05)

VARIABLE, DRIVING

Independent or extrinsic influences that cause a system to function, but which are themselves not affected by the system. See VARIABLE, STATE. (20)

VARIABLE, RATE PROCESS

A variable in a simulation model that describes the physical movement of materials between state variables and which (by definition) ceases to exist when the system is at rest. (20)

VARIABLE, STATE

In systems engineering terminology, a state variable is an interactive component of the system that varies over time and whose value at each point in time reflects the condition or "state" of that system. Where applied to systems ecology, the term refers to an ecosystem component the state of which both influences and is influenced by the conditions of other state variables in that system. Ecosystem state variables interact with each other through abiotic or biotic feedback mechanisms. See VARIABLE, DRIVING. (20)

VARIANCE

A measure of the dispersion of a set of values around their mean, defined as the expected value of the square of the difference between a value and the mean. (04; 05; 12)

VOUCHER SPECIMEN

A specimen retained in a collection as a typical representative of a given population. Such specimens are presumed to be accurately identified by competent authorities. (Light)

WASHERY REFUSE

The refuse removed from newly mined coal at preparation plants. (09)

WATER QUALITY

A term used to describe the chemical, physical, and biological characteristics of water in respect to its suitability for a particular use. (29)

WATER-QUALITY CRITERIA

The types and concentrations of pollutants that affect the suitability of water for a given use. (19)

WATER-QUALITY INDEX

An index developed through either an arithmetic or geometric model, which includes quantitative data from certain basic water-quality indicators and which allows a ranking of the quality of natural waters according to excellent, very good, good, poor, bad or other similar categorization, based on accompanying numerical ranking from 0 to 100. (Delfino)

WATER-QUALITY STANDARD

A plan for water-quality management specifying: the use to be made of the water (recreation, fish and wildlife, drinking water, industrial or agricultural); criteria with which to measure and protect these uses; implementation and enforcement plans; and an autodegradation statement to protect existing water quality. (07)

WATERSHED

1. United States usage: The total area above a given point on a stream that contributes water to the flow at that point. The entire region drained by a waterway or that drains into a lake or reservoir. (10)

2. British usage: The topographic dividing line from which different surface streams flow in two separate directions; the line separating two contiguous drainage areas. (10)

WATER TABLE

The upper surface of the groundwater or that depth below which the soil is saturated with water. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water. In wells that penetrate to greater depths, the water level will stand above or below the water table if an upward or downward component of groundwater flow exists. (11)

WELL HEAD

The point at which oil or gas is brought to the surface, ready for transportation to refinery or ship or pipeline. (08)

WET-TYPE COOLING TOWER

See COOLING TOWER, WET-TYPE

WILDLIFE

1. U.S. Forest Service usage. All nondomesticated mammals, birds, reptiles, and amphibians living in a natural environment, including both game species and nongame species, whether considered beneficial or otherwise. Feral animals such as wild horses, burros, and hogs are not considered wildlife. (10)

2. Undomesticated vertebrate animals, except fishes, considered collectively. (10)

3. Generally, all nondomesticated animal life. (10)

4. More particularly, a loose term that includes nondomesticated vertebrates especially mammals, birds and fishes and some of the higher invertebrates (such as crabs, crayfish, etc.). (10)

5. Living things that are neither plant, nor human, nor domesticated; especially the mammals, birds, and fishes that are hunted by man for sport or food. (10)

XERIC

Refers to a dry habitat, especially as found in desert ecosystems. See HYDRIC; MESIC. (02)

ZOOPLANKTON

The animal portion of the plankton. See PHYTOPLANKTON; PLANKTON. (ECI)

ADDENDUM

EMERGENT PROPERTIES

New characteristics arising unexpectedly through the interaction of several variables, such characteristics not being evident in the separate variables. See HOLISM: SYNERGISTIC EFFECTS.

IRRETRIEVABLE

Not recoverable or correctable; unable to remedy the (ill) effects of. (ECI)

IRREVERSIBLE

Not able to change the direction of, as in an ongoing act or process. (ECI)

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APPENDIX C

Annotated Bibliography of Superior References

INTRODUCTION

This "Annotated Bibliography of Superior References" is intended as a companion document to the main text of the manual. The bibliography is offered as a means of penetrating the tremendous volume of literature that relates in one way or another to the purpose and practice of ecological baseline studies for energy-development activities.

Two hundred and thirty-four references are included. These documents represent a large sample of the best reference material available to baseline study participants. However, it has not been possible to identify and include all existing references that could be judged superior. Omissions and errors have undoubtedly occurred.

Throughout the preparation of this bibliography, "Superior" has been equated with "most useful" -- most useful in the sense that the references included here are among the best available for (1) amplifying theoretical material presented elsewhere in the manual or (2) providing practical "how to" information on accomplishing the procedures and sampling methodologies presented in the manual. The annotation following each reference briefly describes the contents of the document that are of interest to the person who is using this manual as a guide for designing, reviewing, or conducting an ecological baseline study.

Literature cited here is presented in alphabetical order according to the last name of the author. The annotation for each document directly follows the citation. The numbers to the left of the citations are used to identify references in the index which follows the list of citations. All citations have been indexed according to the subject matter dealt with.

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- MEDIUM BIRDS

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  Lizards: 177, 179, 201, 207
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1. Albers, Peter H. 1976. Determining population size of territorial red-winged blackbirds. Journal of Wildlife Management 40(4):761-768.

Area counts of territorial males and roadside estimates (Peterson-Lincoln index are compared as techniques for estimating population density of redwinged blackbirds. Analysis of covariance is used to determine the relative effectiveness of the two techniques. Potential sources of sampling error are discussed, as are the specific merits of the two techniques.

2. Alcorn, J. R. 1971. A discussion on coyote census techniques. U.S. Bureau of Sport Fisheries and Wildlife. Division of Wildlife Services. 8 pp. typescript.

This paper discusses the merits and applicability of the siren-elicited howling response as a method for censusing coyotes over large areas. Previous papers by Alcorn are listed. Examples of station soundings and responses are presented. Recommendations in using the siren census are: noises be avoided; siren be sounded for 2 complete pitch cycles; response be recorded for a 1-minute period, then a 2-minute period; surveys be conducted when the North Star is visible; surveys be conducted in the fall of the year.

3. Alden, Howard R. 1974. Environmental Impact Assessment - A Procedure for Coordinating and Organizing Environmental Planning. Technical Publication No. 10. Thorne Ecological Institute, Boulder, Colorado. 32 pp.

Environmental impact assessment methods were tested on several proposed landuse changes in the Rocky Mountain West. The methods are designed not only to systematize factual data where possible, but also to substantiate value judgements so that decisionmakers and the public can come to logical conclusions regarding the environmental costs for an array of proposed landuse changes. Although the systems for organizing and documenting information are good, the specific treatment of biological information is poor.

4. American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1971. Standard Methods for the Examination of Water and Wastewater, 13th ed. American Public Health Association, Washington, D.C. 874 pp.

A standard reference on methods for chemical analysis of water. Contains sections on biological sampling and analysis of plankton, periphyton, and macroinvertebrates.

5. Anderson, Allen E., Dean E. Medin, and David C. Bowden. 1972. Mule deer fecal group counts related to site factors on winter range. Journal of Range Management 25(1):66-68.

The authors used regression analyses to investigate the relationship between the occurrence of mule deer pellet groups and several vegetative habitat components. Habitat components investigated include percent ground cover, browse yields, and browse utilization.

6. Anderson, David R., Jeffrey L. Laake, Bradford R. Grain, and Kenneth P. Burnham. 1976. Guidelines for Line Transect Sampling of Biological Populations. Utah Cooperative Wildlife Research Unit, Utah State University, Logan, Utah. 27 pp.

The authors investigated the relative merits of various modifications of the line-transect faunal-sampling technique. Numerous theoretical and practical considerations were taken into account along with field verification to derive a list of 10 important points to consider in designing line transect surveys.

7. Arnold, J. F., and H. G. Reynolds. 1943. Droppings of Arizona and antelope jack rabbits and "pellet census." Journal of Wildlife Management 7:322-327.

A laboratory study was conducted to obtain an estimate of the number of pellets defecated per day per jack rabbit. The character of the forage had the greatest effect on the pellet weights. The pellet count remains constant, on the average, irrespective of age, sex, size, or species of jack rabbit. The average pellet count found for jack rabbits eating natural, green, forage material was 531±27 pellets per day.

8. Atkinson, I. A. E. 1975. A method for permanent transects in vegetation. Tuatara (Wellington) 21(3):81-90.

The methodology described is a flexible, useful technique for recording a wide variety of distributional data on forest or grassland plant communities.

9. Avery, A. E. 1968. Interpretation of aerial photographs, 2nd ed. Burgess Publishing Co., Minneapolis, Minnesota. 324 pp.

Methods of aerial photograph interpretation are described for ecological and landuse studies. Types of information obtained from aerial photographs and from vegetation and landuse mapping techniques are given.

10. Barret, Gary W., George M. Van Dyne, and Eugene P. Odum. 1976. Stress ecology. BioScience 26:192-194.

This article presents a ten-point approach to the study of stress effects on ecosystems. It emphasizes integrative techniques, both structural and functional ecosystem parameters, and a balance of the biological, physical, and social sciences in stress evaluation. It is an excellent summary of key points that need to be addressed in future studies of environmental perturbations.

11. Baxter, W. L., and C. W. Wolfe. 1973. Life History and Ecology of the Ring-Necked Pheasant in Nebraska. Nebraska Game and Parks Commission, Lincoln, Nebraska. 58 pp.

In addition to the information outlined in the title, this paper describes field methodologies for studying nesting, brooding, cover-utilization, and harvest of the ring-necked pheasant.

12. Bear, G. D. 1969. Evaluation of Aerial Antelope Census Technique. Game Information Leaflet No. 69. Colorado Division of Wildlife, Denver.

A discussion of the effects of weather, aircraft type, and behavior on the aerial census of antelope.

13. Bella, David A., and W. Scott Overton. 1972. Environmental planning and ecological possibilities. Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineering 98:579-592.

This is one of the more influential papers used in developing the conceptual framework for this manual. The paper presents a number of the conceptual weaknesses of past ecological baseline studies, emphasizes the need for an effective "strategy" of baseline study, and explores some important aspects of the needed strategy.

14. Bender, Gordon L., James MacMahon, and Sigurd Szerlip. 1972. Development of Techniques For Estimating Biomass of Desert-inhabiting Invertebrate Animals. U.S. International Biological Program Desert Biome Research Memorandum RM72-11.

A description of methods for quantitative sampling of invertebrates on small shrubs, in leaf litter and in the soil. Techniques discussed include: Tullgren funnels and flotation, for separating invertebrates from soil, suction traps for sampling plants, and pit traps for surface soil invertebrates.

15. Bennett, C. L., Jr. 1967. A new method for estimating numbers of duck broods. Journal of Wildlife Management 31(3):555-562.

Waterfowl broods are estimated by using a formula based on the assumption that as the number of different broods seen increases it is more difficult to record a new brood. New broods are separated from previously recorded broods by records of species, brood age, and number in brood. The technique should be useful for small impoundments and marshes on energy development sites.

16. Best, Louis B. 1975. Interpretational errors in the "mapping method" as a census technique. The Auk 92:452-460.

Five ecologists were given data derived by the "mapping method" and asked to interpret them in numbers of breeding pairs. The variability among their results is discussed and their results compared with the known population size derived from a marking program. This study provides valuable insight into the various interpretational errors that can be made in estimating population density and territorial boundaries using this technique.

17. Black, S. A. 1965. Methods of Soil Analysis, Parts 1 and 2. Agronomy No. 9, American Society of Agronomy, Madison, Wisconsin. 1572 pp.

One of the standard references for methods of physical and chemical soil analysis. Detailed procedures for analysis of soils are provided.

18. Brady, Nyle C. 1974. The Nature and Properties of Soils, 8th ed. Macmillan Publishing Co., New York. 639 pp.

A good general text that provides descriptions and discussion of the origin and classification of soils. Of particular interest are the chapters dealing with the organic components of soil formation and evolution. Nutrient properties of soils, soil moisture and plant relationships, and soil microorganism interactions are also discussed. Soil chemistry and physical properties are discussed relative to their effects on plant vigor and productivity.

19. Brewer, Richard. 1972. An evaluation of winter bird population studies. The Wilson Bulletin 84(3):261-277.

The winter bird population studies published annually in American Birds (formerly Audubon Field Notes) is the only large body of data on population sizes of birds during the winter season. A frequent warning accompanying the publication of the results of these studies is that the methodology utilized makes analysis and interpretation of results a difficult and uncertain task. This paper presents results from a model devised to assess the meaning of results reported in American Birds. As such, the paper presents important information useful to those investigators who would either utilize the large volume of data reported over the years, or utilize a similar method for gathering data on winter bird populations.

20. Brower, J. E., and J. H. Zar. 1977. Field and Laboratory Methods for General Ecology. William C. Brown and Co., Dubuque, Iowa. 194 pp.

General techniques manual for ecological sampling and data analysis, including sections on the analysis of habitats, populations, communities, and production, and discussions of many plant and animal sampling methods.

21. Brown, Leslie. 1974. Data required for effective study of raptor populations. Raptor Research Report 2:9-20.

According to the author, raptor population studies require data on the physical characteristics, food requirements, food preferences, breeding dynamics, and survival rate of young of the species. The author gives general examples of the way these data have been collected in the past and suggests ways of standardizing the approach for future studies of raptor populations.

22. Brun, J. M., and Thadis W. Box. 1963. A comparison of line intercept and random point frames for sampling desert shrub vegetation. Journal of Range Management 16:21-25.

The two techniques listed in the title were used to obtain cover and composition data in two shrub-grass vegetation types of northern Utah. The paper compares the relative efficiency of the techniques in attaining given levels of confidence. The point-frame technique was more efficient for estimating both cover and composition.

23. Buol, S. W., F. D. Hole, and R. J. McCracken. 1973. Soil Genesis and Classification. Iowa State University Press, Ames, Iowa. 360 pp.

    Soil characteristics are defined and explained in considerable detail. Of particular value are the discussions of biological influences on the formation and modification of soils. Soil classification systems are described and modern systems based on age, structural characteristics, parent materials, climatological and biological factors are discussed in some detail.

24. Bureau of Land Management. No Date. Bureau of Land Management Manual 4412 -Physical Resources Studies. U.S. Bureau of Land Management, Washington, D.C. pp. discontinuous.

    This manual serves as a standard methods manual for BLM range inventories. The manual includes methods for mapping, measuring forage production, and estimating forage utilization. Field procedures and ocular reconnaissance are discussed in detail.

25. Bureau of Land Management. No Date. Bureau of Land Management Manual 6000 - Wildlife Habitat Management System. Bureau of Land Management, Washington, D.C. pp. discontinuous.

    Contains information, procedures, and directions for planning and conducting a wildlife habitat management program. This program includes: recognition of wildlife species' life histories and habitat requirements; inventory and analysis of habitat; and planning, conducting, and evaluating management.

26. Bureau of Land Management. 1976. Big game range analysis techniques notebook. Bureau of Land Management, Denver. pp. discontinuous.

    Numerous methodologies and guidelines relating to big game studies are contained in this notebook. Many are standard study methods that have been developed by specific state BLM offices. Methods are presented for estimating stand composition, analyzing browse, analyzing condition of browse, and evaluating animal concentrations. The adequacy and applicability of various methods are discussed.

27. Burton, T. M., and G. E. Likens. 1975. Energy flow and nutrient cycling in salamander populations in the Hubbard Brook Experimental Forest, New Hampshire. Ecology 56:1068-1080.

    The study combines two approaches to assessing the role of salamander populations in ecosystem function: energy flow and nutrient cycling. Salamanders were analyzed for calcium, magnesium, potassium, sodium, nitrogen, sulfur, and zinc content. Energy flow through salamander populations was measured as kCal/hectare/year.

28. Cain, S. A., and G. M. de Olivera Castro. 1959. Manual of Vegetation Analysis. Harper, New York. 325 pp.

    The manual contains many of the concepts of vegetation analysis developed by botanists, and describes the basis for these concepts and the field techniques that have been found useful in developing and applying them.

Methods range from extensive studies of large areas of heterogeneous vegetation to others applicable to intensive investigations of small areas, single communities, and simple stands. A valuable text for interpreting vegetation data.

29. Carley, C. J. 1973. Development of a Coyote Census Technique. Presented at the Annual Meeting of the Colorado Chapter of the Wildlife Society and the Colorado Section of the Society of Range Management. U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Denver. 17 pp. typescript.

The two most viable coyote census techniques are the siren-elicited howling response and the scent station visitation technique. The paper describes both techniques and compares the strengths and weaknesses of each.

30. Caughley, Graeme. 1974. Bias in aerial survey. Journal of Wildlife Management 38(4):921-933.

Factors that detract from the accuracy of population estimation from large-mammal aerial surveys are discussed in this article. An evaluation of potential refinements to the technique to eliminate this bias suggests there is no technical solution. The authors do suggest a method of measuring the bias and applying correction factors to the aerial survey results to derive an unbiased population density estimate.

31. Caughley, Graeme, Ronald Sinclair, and Donald Scott-Kemmis. 1976. Experiments in aerial survey. Journal of Wildlife Management 40(2): 290-300.

Evaluations are made of the effects of several variables on the accuracy of aerial survey estimates of population density. Biases can be corrected by appropriate regression of observed density on horizontal speed, height, and transect width, the three most influential variables. Field experiments used an unknown-size population of red kangaroos, and a known-size sheep population. Laboratory experiments used simulated transect counts of projected dot patterns. All experiments were designed to be amenable to analysis of variance.

32. Chow, Ven Te, (ed.). 1966. Handbook of Applied Hydrology. McGraw-Hill Book Co., New York. 1418 pp.

This comprehensive handbook presents a wealth of useful information on virtually all areas of hydrology. It contains complete, authoritative coverage of the basic theories, principles, and data required for the study and management of water and water-resources projects.

33. Christenson, N. 1969. Soil microfungi of dry to mesic conifer-hardwood forests in northern Wisconsin. Ecology 50:9-27.

Soil microfungi were surveyed in Wisconsin conifer-hardwood forests utilizing the dilution-plot technique. Estimates of frequency and relative densities of species were obtained and used to assess species importance.

34. Cochran, George A., and Howard J. Stains. 1961. Deposition and decomposition of fecal pellets by cottontails. Journal of Wildlife Management 25(4):432-435.

This article evaluates the reliability of estimates of rabbit population density by using pellet counts. The authors report wide variability in both deposition and decomposition rates and discuss the factors contributing to these differences. The authors conclude that rate variations make population estimations from pellet counts unreliable, and they suggest that more basic research is needed before pellet counts can become useful methods for estimating population density.

35. Cochran, W. G., and G. M. Cox. 1957. Experimental Designs, 2nd ed. John Wiley and Sons, New York. 611 pp.

This is a basic reference for applying and interpreting experimental design procedures. It requires a good background in statistics.

36. Cochran, W. G. 1963. Sampling Techniques, 2nd ed. John Wiley and Sons, New York. 413 pp.

This advanced text presents a comprehensive account of sampling theory with illustrations of practical applications. A sound background in mathematics and statistics is required.

37. Cole, Glen F. 1976. Management Involving Grizzly and Black Bears in Yellowstone National Park, 1970-75. Natural Resources Report No. 9. National Park Service.

Hypotheses were evaluated to test the effectiveness of management practices for the two bear species in Yellowstone Park. Management goals are to decrease bear attacks, restore natural spatial distribution and ecological interactions, and preserve bear population stability. Available data on injuries, distribution, and control suggest that current management practices are meeting these goals. The primary value of the article is the presentation of a statistical evaluation technique potentially applicable to predictive assessments of changes in baseline conditions resulting from industrial development.

38. Cook, C. W., and C. D. Bonham. 1977. Techniques for Vegetation Measurements and Analysis for a Pre- and Post-Mining Inventory. Range Science Series No. 28. Colorado State University, Fort Collins. 82 pp.

The manual was developed in response to vegetation sampling requirements for western mine sites. It includes field methods for describing rangeland vegetation communities, including productivity estimates. Treatment of statistical considerations is aimed at assuring valid pre- and post-mining comparisons.

39. Cottam, G., and J. T. Curtis. 1956. The use of distance measures in phytosociological sampling. Ecology 37:451-460.

Data obtained from four different distance methods for the sampling of plant communities in composition studies are compared with results obtained using the quadrat method. The quarter method gives the least variable results, is least susceptible to subjective bias, and requires fewer sample points.

40. Cowardin, Lewis M., and Victor I. Myers. 1974. Remote sensing for identification of wetland vegetation. Journal of Wildlife Management 38(2): 308-315.

Describes use of multispectral (color, color infrared, black and white) aerial photography, ground truthing, and aerial photo-interpretation in identifying and mapping wetlands vegetation.

41. Cowardin, Lewis M., Virginia Carter, Francis C. Golet, and Edward T. LaRoe. 1976. Interim Classification of Wetlands and Aquatic Habitats of the United States. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. 109 pp.

A new system of wetlands classification for the United States. The manual is intended to replace Circular 39 (Martin et al. 1953) as the standard reference for describing and classifying wetlands. Wetland terms and definitions are provided.

42. Cox, G. W. 1972. Laboratory Manual of General Ecology. W. C. Brown, Dubuque, Iowa.

General techniques manual for ecological sampling and data analyses. Vegetation sampling techniques described include quadrat sampling, plotless sampling, line intercept, and the Bitterlich variable-radius technique.

43. Craighead, J. J., and F. C. Craighead. 1969. Hawks, Owls, and Wildlife. Dover Publications, Inc., New York. 443 pp.

A large amount of information is provided on life histories, food habits, and behavior of raptors. Census techniques described include roadside counts, ground counts, mapping, total counts, roost counts, and nest counts.

44. Craighead, J. J., J. R. Varney, and F. G. Craighead, Jr. 1974. A population Analysis of the Yellowstone Grizzly Bears. Montana Forest and Conservation Experiment Station Bulletin 40. University of Montana, Missoula. 20 pp.

Grizzly bear population data gathered over a 15-year period in Yellowstone Park are summarized, and the derivation of a mathematical model of this population is described. The validity of the model is verified by

comparing its behavior with that of the actual population during the period for which field data were available.

45. Cunningham, G. M. 1975. Point quadrats to measure ground cover in rangelands - a review. Journal of Soil Conservation Service, New South Wales 31(3):193-197.

This article reviews the development and utility of the point quadrat as a technique for measuring percent ground cover, relative frequency, and percent pasture cover. The technique is most useful in arid and semiarid grassland-range plant communities.

46. Daniel, Walton S., and D. B. Frels. 1971. A Track-Count Method for Censusing White-Tailed Deer. Texas Parks and Wildlife Department Technical Series No. 7. 18 pp.

The methodology presented utilizes track counts as an index of abundance.

47. Daubenmire, R. 1968. Plant Communities: A Textbook of Synecology. Harper and Row, New York. 300 pp.

This text describes the science of plant community study. Community ecology of the major community types in the United States and Europe is described. The text also presents a number of field and laboratory methods and the rationale for design procedures.

48. Davis, Stanley N., and Roger L. M. De West. 1966. Hydrogeology. John Wiley and Sons, Inc., New York. 463 pp.

This text treats, in a basic format, the occurrence, movement, and physical/chemical properties of groundwater. It provides a good balance between geology, hydraulics, and hydrology necessary for development of an accurate, rational and practical understanding of groundwater resources. Good explanation of exploration and drilling techniques further enhance this understanding.

49. Diem, Kenneth L., and K. H. Lu. 1960. Factors influencing waterfowl censuses in the Parklands, Alberta, Canada. Journal of Wildlife Management 24(2):113-133.

Various environmental and human factors influence the accuracy of aerial waterfowl censuses. Breeding population and brood population aerial censuses are influenced by waterfowl characteristics, seasonal vegetation developments, human error, time of day, and weather conditions. Aerial census results are compared with roadside counts and ground beat-out censuses.

50. Diem, Kenneth L. 1976. An Avian Monitoring and Rapid Information Retrieval System. Wildlife Technical Report No. 5. Wyoming Game and Fish Department, Cheyenne. 81 pp.

The organizational framework and the methodology for a standardized statewide (Wyoming) avian census are presented. The procedures will be utilized to provide the following information on Wyoming breeding bird populations: species composition, density, relative abundance, indices of baseline population levels for particular habitat associations, breeding diversity, nest site characteristics, and general natural history. Standardized forms for recording this information are provided. The report is useful to baseline design. The data base which this system will be used to collect, could become a valuable information source for future ecological baseline programs.

51. Dietrick, E. J., E. I. Schlinger, and R. Van Den Bosch. 1959. A new method for sampling arthropods using a suction collecting machine and a modified Berlese funnel separator. Journal of Economic Entomology 52:1085-1091.

The methodology and equipment described are used in quantitative sampling of arthropod populations. A critique of the method is included.

52. Dochinger, L. J., and T. A. Seliga. 1976. Proceedings of the First International Symposium on Acid Precipitation and the Forest Ecosystem. U.S. Department of Agriculture Forest Service General Technical Report NE-23. Northeast Forest Experimental Station, Upper Darby, Pennsylvania. 1074 pp.

This is the most comprehensive review of acid precipitation and its potential impacts on ecosystems of any existing publication. The initial section covers atmospheric transport and chemistry, including the effects of various pollutants on atmospheric chemistry, and the analytical techniques used to evaluate precipitation chemistry. Later sections examine the effects of changes in precipitation chemistry on soils, aquatic systems and forest vegetation. While our understanding of acid precipitation is rapidly evolving, the information in this publication clearly illustrates areas of concern and demonstrates the approaches being employed to evaluate precipitation chemistry.

53. Dolbeer, R. A., and W. R. Clark. 1975. Population ecology of snowshoe hares in the central Rocky Mountains. Journal of Wildlife Management 39(3):535-549.

This paper reports the results of investigations aimed at estimating local densities of snowshoe hares; examining natality rates, survival rates, movements, and population dynamics; and comparing these results with results from published investigations of snowshoe hares at higher latitudes. The major data source was live-trapping-grid results. Home range was estimated using a boundary-strip method and population density was estimated using Jolly's stochastic model. Reproductive biology information was obtained from palpation and autopsy results. Fecal pellet counts provided an index of habitat preference. Results are discussed in some detail and conclusions are supported by a good literature backup.

54. Dondale, C. D., et al. 1971. An improved Berlese-Tullgren funnel and a flotation separator for extracting grasslands arthropods. Canadian Entomology 103:1549-1552.

Describes a funnel extraction technique that efficiently removes grassland arthropods from coarse plant material. A saltwater flotation separator to extract arthropods from fine litter and soil is also described.

55. Dozier, Herbert L. 1953. Muskrat Production and Management. Circular 18, Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C. 42 pp.

The text is a good general reference on muskrat ecology. It includes a discussion of methods for estimating population numbers. The primary census method discussed is the count of houses along aerial or ground strip transects.

56. Eberhardt, L. L. 1971. Population analysis, pp. 457-495. In R.H. Giles, Jr., (ed.), Wildlife Management Techniques, 3rd ed. The Wildlife Society, Washington, D.C. 633 pp.

Presents a definition and discussion of population analysis. The mathematics and statistics of survival, recruitment, population structure, and population size and trends are reviewed. Also included are methods of data collection.

57. Eberhardt, L. L. 1975. Sampling for radionuclides and other trace elements. In C. E. Cushing, (ed.), Radioecology and Energy Resources. Special Publication No. 1, The Ecological Society of America.

Offers several methods for improving ecological sampling. Advocates a combination of sampling and modeling for ecosystem studies.

58. Edmondson, W. T., (ed.). 1959. Freshwater Biology, 2nd ed. John Wiley and Sons, Inc., New York. 1248 pp.

A volume containing keys for the identification of algae, macrophytes, and all invertebrate groups occurring in fresh waters of the United States.

59. Edmondson, W. T., and G. G. Winberg. 1971. A Manual on Methods for the Assessment of Secondary Productivity in Fresh Water. International Biological Program Handbook No. 17. Blackwell Scientific Publications, Oxford, England. 358 pp.

This book reviews field methods for sampling zooplankton, macroinvertebrates and includes biomass methods of determining standing crop of zooplankton and macroinvertebrates. It discusses physiological techniques of measuring secondary production.

60. Edwards, W. R., and L. Eberhardt. 1967. Estimating cottontail abundance from livetrapping data. Journal of Wildlife Management 31(1):87-96.

Describes in detail several methodologies for estimating cottontail rabbit abundance from livetrapping data. Data derived from livetrapping a population of known size were analyzed by using several methods and an estimate of abundance was obtained from each. Results allow comparison of the relative accuracy of each method.

61. Emlen, John T. 1971. Population densities of birds derived from transect counts. Auk 88:323-342.

Reviews and evaluates six commonly used techniques for determining bird population densities. Presents in great detail a technique that utilizes counts of observed birds within a variable-width strip transect. This method was compared to other methods and found to be applicable in all seasons, more efficient in number of acres covered per manhour, and comparable in accuracy.

62. Emlen, John T. 1974. An urban bird community in Tucson, Arizona: derivation, structure, regulation. Condor 76:184-197.

Through comparison of two nearby bird communities, one in an urban setting, the other in a nearby desert habitat carefully chosen to resemble the urban site prior to development, the author considers the ecological changes resulting from urbanization and the associated changes in avifauna. The analysis of data and interpretation of variation between the two communities make this an especially superior reference. The line of reasoning applied here can be instructively applied to other situations where natural habitat has been or will be changed.

63. Emlen, John T. 1977. Estimating breeding season bird densities from transect counts. Auk 94:455-468.

This article up-dates an earlier paper (1971) that describes population estimation using a transect count. New or modified procedures are described for recording detections, establishing strip widths, bypassing the calculation of "coefficients of detectability," estimating distances in the field, determining an optimum rate of progress, and measuring the frequency of singing in a representative sample of the population. A comparison of transect and plot census methods is presented.

64. Enderson, James H., Frank A. Colley, and John Stevenson. 1970. Aerial eagle count in Colorado. Condor 72(1):112.

This article discusses eagle data obtained while flying aerial transects for a pronghorn antelope census. Methods and data are presented.

65. Erickson, A. W., J. Nellor, and G. A. Petrides. 1964. The Black Bear in Michigan. Michigan Agricultural Experiment Station Research Bulletin 4. Lansing. 102 pp.

Data on the breeding biology, population structure, movements and mortality of black bears are presented and analyzed.

66. Evans, K. E., and D. L. Gilbert. 1969. A method of evaluating greater prairie chicken habitat in Colorado. Journal of Wildlife Management 33(3):643-649.

A comparison of two prairie chicken habitats in eastern Colorado, supporting consistently different population densities, allowed determination of important habitat characteristics. From this information, a habitat evaluation form was derived. Use of this form allows ranking of areas relative to their overall potential value to prairie chickens and also identifies individual habitat components that may be deficient and in need of improved management.

67. Ferguson, R. B. 1955. The weathering and persistency of pellet groups as it affects the pellet group count method of censusing mule deer. Utah Academy of Science, Arts, and Letters 32:59-64.

This article discusses the aging and decomposition of mule deer pellet groups. Effects of weathering and persistency on pellet-group-count estimates of mule deer population estimates are presented.

68. Flood, B. S., M. E. Sangster, R. D. Sparrowe, and T. S. Baskett. 1977. A Handbook for Habitat Evaluation Procedures. Resource Publication 132. Fish and Wildlife Service, U.S. Department of the Interior. 77 pp.

The handbook was prepared to implement the habitat evaluation procedures for measuring the effects of water development projects on fish, wildlife, and related resources. It is intended to serve as a prototype for development of handbooks for other areas besides Crawford County, Missouri. Environmental information contained in an EIS was used to determine important habitat characteristics. Criteria for scoring each habitat characteristic are presented within each animal group. It is expected that use of these written criteria will foster uniformity (replicability) in the evaluations.

69. Flyger, V. F. 1959. A comparison of methods for estimating squirrel populations. Journal of Wildlife Management 23(2):220-223.

Squirrel populations were estimated using trap-recapture data, trap-sight data, and time-area counts. The Schnabel formula was used for the trap-recapture and trap-sight data. The trap-sight technique was most satisfactory and the time-area count was found to be unsatisfactory.

70. Food and Agricultural Organization of the United Nations. 1976. Indices for Measuring Responses of Aquatic Ecological Systems to Various Human Influences. Fisheries Technical Paper No. 151. F. A. O., Rome. 66 pp.

A critical review of indices useful in measuring, surveying, and monitoring response of aquatic systems to human influence, with special reference to fishery resources. The report gives guidelines for selecting and formulating indices, emphasizes the informational needs of planners and decision-makers and considers cost-effectiveness based on state-of-the-art methods.

71. Foote, Leonard E., and Harold S. Peters, (eds.). 1952. Investigations of Methods of Appraising the Abundance of Mourning Doves. Special Scientific Report - Wildlife No. 17. U.S. Fish and Wildlife Service, U.S. Department of the Interior. 52 pp.

Several papers describing mourning dove census methods are included. Methods described are call counts, road-call counts, roadside counts, and spot mapping.

72. Franzreb, Kathleen E. 1976. Comparison of variable strip transect and spot-map methods for censusing avian populations in a mixed coniferous forest. Condor 78:260-262.

Various disadvantages and advantages are discussed with respect to the variable-strip transect and spot-map methods of avian censusing. The spot-map method can only be used during breeding season when males establish territories and are singing. Variable-strip transects tend to underestimate population sizes where dense vegetation may hamper detectability.

73. French, Norman R. 1977. Ecosystem trophic relationships in habitat classification. Reprint of a paper submitted to Proceedings titled "Classification, Inventory, and Analysis of Fish and Wildlife Habitat" - A National Symposium January 24-27, 1977. Phoenix.

Explores some of the important concepts involved in developing an effective, functional scheme of habitat classification. Reviews the major ecosystem characteristics and current concepts in evolutionary ecology that reflect important components of community organization.

74. Gates, C. E., W. H. Marshall, and D. P. Olson. 1968. Line transect method of estimating grouse population densities. Biometrics 24:135-145.

The analysis of line transect data for grouse by a new technique is compared with estimates using the Hayne, King, and Webb estimator techniques. The new technique uses right angle distances from the observer to the bird flushed. Data analysis methods and methods for determining sample size are included.

75. Gates, C. E., and W. B. Smith. 1972. Estimation of density of mourning doves from aural information. Biometrics 28:345-359.

This article discusses dove call counts and a mathematical method for estimating dove densities. Simulation was used to find a correction factor for the variations in dove calls per unit of time. The method of deriving a correction factor may be applicable to call counts of other species.

76. Gates, J. M. 1966. Crowing counts as indices to cock pheasant population in Wisconsin. Journal of Wildlife Management 30(4):735-744.

Cock pheasant crowing counts were made on an area of known pheasant population in east-central Wisconsin to test four implicit assumptions in the count index and to evaluate the utility of crowing counts as pheasant population indices. One of the four assumptions was rejected. The author claims, for Wisconsin at least, that the crowing count appears to be a reliable index of cock pheasant populations, but stresses the importance of sampling only in optimal weather conditions to minimize sampling error.

77. Gaud, William S., (ed.). 1975. Environmental Impact Studies of the Navajo and Kaiparowits Power Plants. Fourth Annual Report (June 1974-May 1975). Environmental Impact Studies, Northern Arizona University, Flagstaff.

This is an example of an impact assessment project undertaken from a holistic point of view, using a mathematical simulation model as an evaluative and predictive tool. An attempt has been made to focus on the "key" abiotic and biotic components and processes in desert ecosystems. Quality of studies is variable but approaches to measuring net production and evaluating decomposers are especially useful.

78. Gilbert, Gebecca L. 1977. Inventory of Potential Black-Footed Ferret Habitat in the White River Resource Area, Colorado. Cooperative Education Publication No. 1. Bureau of Land Management, Craig District, Colorado. 21 pp.

A portion of the BLM White River Resource Area was surveyed for white-tailed prairie dogs. Prairie dog towns were located and plotted onto USFS, land ownership, and vegetative cover maps to determine land status and habitat preference. Burrow-density transects were used to determine size and density of the town and relative activity. Evidence of black-footed ferret activity was sought but not found in the several prairie dog towns investigated.

79. Gilbert, Paul F., and Jack R. Grieb. 1957. Comparison of air and ground deer counts in Colorado. Journal of Wildlife Management 21(1):33-37.

This investigation shows that under similar counting conditions, aerial counts consistently tally about the same percentage of deer, but that the percentage of deer will vary with changes in snow cover. Ground counts, by the drive method, produced consistently higher numbers of animals than did aerial counts. Aerial counts should not be made in poor flying weather, and flights should be confined to early morning and evening.

80. Golley, F. B., K. Petrusewicz, and L. Ryszkowski, (eds.). 1975. Small Mammals: Their Productivity and Population Dynamics. Cambridge University Press, Cambridge. 451 pp.

This text is one of the best single references of field methods and data analyses for small mammal population studies. Sampling techniques and design assumptions are discussed for productivity and population dynamics studies.

81. Golterman, H. L. 1969. Methods for Chemical Analysis of Fresh Water. International Biological Program Handbook No. 8. Blackwell Scientific Publications, Oxford and Edinburgh. 166 pp.

Laboratory methods for the chemical analysis of fresh water with a discussion of limitations of various levels of analysis.

82. Graber, Richard R., and Jean W. Graber. 1963. A comparative study of bird populations in Illinois, 1906-1909 and 1956-1958. Illinois Natural History Survey Bulletin 28:383-528.

An application of the direct strip count as an avian census technique. Contains population data useful for comparative purposes. Also presents some interesting generalizations regarding the response of avian communities to increased habitat specialization resulting from human management.

83. Grieg-Smith, P. 1964. Quantitative Plant Ecology, 2nd ed. Butterworths, London. 256 pp.

This classic in its field deals with a statistical approach to sampling and comparing, pattern analysis, species association, and correlation of vegetation with habitat factors. A must for all ecologists concerned with vegetation studies.

84. Gray, D. M., ed. 1973. Handbook on the Principles of Hydrology. Water Information Center, Inc., Port Washington, New York. 689 pp.

General text encompassing the basic principles of hydrology with special emphasis on prairie conditions in Canada. Provides a strong theoretical basis for understanding the various natural phenomena. Bridges the gap between a basic text and a traditional handbook.

85. Hahn, Henry C., Jr. 1949. A Method of Censusing Deer and Its Application in the Edwards Plateau of Texas. Texas Game, Fish, and Oyster Commission, Austin. 24 pp.

Excessive deer mortality on the Edwards Plateau prompted the evaluation of population estimation techniques. Aerial surveys are compared with riding (road) cruise and walking cruise counts. Walking cruise counts appear to be most effective in the dense underbrush of the area. Optimum survey design characteristics are described. Population and sex ratio estimates were made for deer and domestic livestock to aid in management planning for the area.

86. Hanson, William R. 1963. Calculation of productivity, survival, and abundance of selected vertebrates from sex and age ratios. Wildlife Monographs 9:1-60.

A review of methods for calculating productivity, survival rate, and abundance using previously obtained data on sex and age ratios. The methods are mathematically valid for any species on which valid data can be obtained.

87. Hartman, R. M. 1975. Development of a guide for aquatic ecological surveys, pp. 771-784. In Environmental Effects of Cooling Systems at Nuclear Power Plants. Proceedings of symposium, OSLO, August 1974, The International Atomic Energy Agency, Vienna.

This paper expresses some good ideas that are useful to the theoretical framework of the manual, including some very useful matrices for defining parameters of aquatic systems. Supplies guidance for the scope and detail of aquatic ecological studies.

88. Hay, Keith G. 1958. Beaver census methods in the Rocky Mountain Region. Journal of Wildlife Management 22(4):395-402.

Beaver colonies were accurately estimated using aerial and ground counts of the number of food caches in a given area in late September or October. Lodge counts were not closely related to the number of colonies. The number of beavers per colony was estimated through dead-trapping, as live-trapping was unreliable in estimating colony size.

89. Hayne, Don W. 1949. An examination of the strip census method for estimating animal populations. Journal of Wildlife Management 13(2):145-147.

This article is one of the first published on strip censuses for estimating animal populations. The formula used in calculating the population estimate uses the flushing distance in the calculation of the area censused. The method uses individual flushing distances rather than an average flushing distance for all individuals.

90. Hem, John D. 1970. Study and Interpretation of the Chemical Characteristics of Natural Water. Geological Survey Water-Supply Paper No. 1473. U.S. Geological Survey, Washington, D.C. 393 pp.

Discussions of the occurrence of chemical constituents of natural waters and the interpretation of analytical results.

91. Henderson, F. R., P. F. Springer, and R. Adrian. 1974. The Black-Footed Ferret in South Dakota. South Dakota Department of Game, Fish, and Parks, Pierre. 37 pp.

Information on the life history and past and present distributions of the black-footed ferret is provided. Suggested methods for study and observation are given, as are photographs and descriptions of definitive sign. Presence of sign, other than direct observation of black-footed ferret, will only indicate past presence. Needs for future research and additional information are outlined.

92. Hirsch, Allen. 1976. The Baseline Study as a Tool in Environmental Impact Assessment. Symposium on Biological Evaluation of Environmental Impact. 27th Annual Meeting, American Institute of Biological Sciences, New Orleans.

Hirsch, chief of the Office of Biological Services, U.S. Fish and Wildlife Service, makes some good points about the utility of baseline studies and the kinds of parameters usefully measured in such programs. This paper illustrates the convergence of current thinking occurring among environmental scientists and environmental regulators.

93. Holmberg, Nevin D. 1977. The Habitat Evaluation Procedures: A Test of Replicability. Ecological Services Memorandum Report No. 1, Division of Ecological Services, U.S. Fish and Wildlife Service. 15 pp.

Replicability of habitat evaluation procedures was tested in the six service regions (12 habitat types) using two or three evaluation teams per habitat type. Of 36 sets of comparisons, 26 accepted the null hypothesis (no average habitat unit value differences) at the 95 percent level. Of the 10 comparisons in which the null hypothesis was rejected, nine were for known and correctable causes not related to the evaluation procedure itself. Results suggest that replicability is good for the habitat evaluation procedures as long as adherence to procedures is firm.

94. Hopper, R. M. 1967. Air-Ground Comparison Counts of Breeding Ducks in the San Luis Valley. Outdoor Facts, Game Information Leaflet No. 61, Colorado Division of Game, Fish and Parks, Denver. 3 pp.

Discusses the need for air-ground comparison studies to further refine estimates of breeding population size in ducks. These should be conducted each year as visibility can vary from year to year.

95. Hungerford, C. R., C. H. Lowe, and R. L. Madsen. 1974. Population Studies of the Desert Cottontail (*Sylvilagus audubonii*), Black-tailed Jackrabbit (*Lepus californicus*) and Allens Jackrabbit (*Lepus alleni*) in the Sonoran Desert. U.S. International Biological Program, Desert Biome Memorandum 74-23. 22 pp.

Presents a strip census technique for estimating abundance of lagomorphs that is applicable to cultivated areas, prairies, and grasslands. Provides basic information on the effects of site variables (precipitation, plant phenology, and vegetation quantity) on reproductive rate. However, limited study length (2 3/4 years), small sample size, and differences in census areas allowed only tentative conclusions on the effects of the site variables on reproductive rate.

96. Husch, B., C. I. Miller, and T. W. Beers. 1972. Forest Mensuration. Ronald Press Co., New York. 410 pp.

This is a standard text for methods of evaluating the commercial value of woodlands. Methods are included for estimating volumes of timber, poles, and pulpwood.

97. Hutchinson, G. E. 1957. A Treatise on Limnology, Volume 1; Geography, Physics, and Chemistry. John Wiley & Sons, Inc., New York. 1015 pp.

This is the most comprehensive discussion of formation of lake basins and the physical and chemical factors operating in their waters.

98. Hynes, H. B. N. 1960. The Biology of Polluted Waters. Liverpool University Press, Liverpool. 202 pp.

A discussion of natural communities in running water and how they are affected by pollution, primarily by domestic sewage.

99. Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press, Toronto. 555 pp.

A discussion of major physical and chemical factors in running waters and how these relate to the biota. Excellent summaries of the ecological and biological relationship of plants and animals in running water.

100. Intersociety Committee. 1977. Methods of Air Sampling and Analysis, 2nd ed. American Public Health Association, Washington, D. C. 1000 pp.

This publication is the product of the combined efforts of ten scientific societies. It introduces the various sampling techniques, analytical techniques and sample handling and processing procedures in Part I. The next sections of the book present specific analytical techniques for various classes of pollutants: carbon compounds, halogen compounds, metals, oxidant and inorganic nitrogen compounds, particulates, radioactivity and sulfur compounds. The book is comprehensive in scope and covers each pollutant thoroughly. A thorough understanding of the information presented for each pollutant is fundamental to the establishment of a pollutant-monitoring program.

101. Jarvinen, O., and R. A. Vaisanen. 1975. Estimating relative densities of breeding birds by line transect method. Oikos 26(3):316-322.

The use of line transects (strip transects) in making relative abundance estimates was studied. The effect of distance on detectability was studied through the use of mathematical models. The models used demonstrated that data for species with long flushing distances could be used and that these individuals are commonly the species that are less abundant and for which few data are available.

102. Johnson, L. F., E. A. Curl, J. H. Bond, and H. A. Fribourg. 1959. Methods for Studying Soil Microflora-Plant Disease Relationships. Burgess Publishing Co., Minneapolis.

A handbook of techniques for isolating and culturing soil microorganisms. Includes brief sections on experimental design and data analysis.

103. Johnson, L. F., and E. A. Curl. 1972. Methods for Research on the Ecology of Soil-Borne Plant Pathogens. Burgess Publishing Co., Minneapolis.

An update of a previous volume (Johnson et al. 1959), this compilation of methodologies for studying soilborne plant pathogens is designed for use as a laboratory manual. Many methods are outlined in detail.

104. Johnson, Philip L., (ed.). 1969. Remote Sensing in Ecology. University of Georgia Press, Athens. 244 pp.

A collection of papers describing the use of remote sensing in ecological studies. Techniques include color photography, infrared photography, spectrophotometry, and multispectral analysis.

105. Johnson, Philip L., (ed.). 1976. Role of Ecology in Environmental Management. Report of a Workshop, September 9-11, 1976. Oak Ridge Associated Universities, Oak Ridge, Tennessee. 23 pp.

This report presents the synthesis of a workshop on the role of ecology in the management of environmental problems. It emphasizes the need to couple ecological information to resource management information needs. The workshop considered the various users of ecological information and their requirements, and outlined a conceptual template for relating ecological applications to management needs.

106. Kadlec, J. A., and W. H. Drury. 1968. Aerial estimation of the size of gull breeding colonies. Journal of Wildlife Management 32(2):287-293.

This paper reports an analysis of the accuracy of aerial censuses and aerial photography as measures of gull breeding populations on islands in Massachusetts Bay and in Maine. Comprehensive ground nest counts were used to evaluate the accuracy of aerial observer estimates and photointerpretation. Discussion of the comparisons are statistically well-supported. Diurnal fluctuation in nest occupancy detracts seriously from photointerpreted counts. Results suggest breeding gull numbers would have to change about 25 percent before photographic techniques would reliably record the change.

107. Kendeigh, S. C. 1944. Measurement of bird populations. Ecological Monographs 14:67-106.

A review of the early bird-census techniques, including those for estimating both absolute and relative abundance. Many of the techniques are similar to current methods and sampling assumptions are still applicable.

108. Kent, J. W. 1972. Application of statistical techniques to the analysis of fungal populations. Transactions of the British Mycological Society 58:253-268.

A series of soil isolation plates were utilized as the mycological equivalent of point quadrat sampling pins. A set of non-normal data was analyzed using parametric and non-parametric methods. It was concluded that non-parametric tests may be a good alternative to parametric tests for the analysis of non-normally distributed presence and absence records.

109. Klein, D. A., P. A. Mayeux, and S. L. Seaman. 1972. A simplified unit of evaluation of soil core respirometric activity. Plant and Soil 36:177-183.

The article describes a simplified respirometer capable of measuring oxygen uptake and carbon dioxide evolution of large soil samples over extended periods. Respirometric activity is calculated using conventional manometric procedures. Advantages of the respirometer are low cost, simplicity, and procedural validity.

110. Kline, Paul D. 1965. Factors influencing roadside counts of cottontails. Journal of Wildlife Management 29(4):665-671.

Results are presented for numerous early morning roadside counts of cottontails conducted over a single 30-mile route in east-central Iowa during a 3-year period. The effect of time of day, weather factors, and seasonal activity patterns are evaluated statistically. Possible factors contributing to seasonal variations in cottontail activity patterns are discussed.

111. Knight, F. B. 1966. Evaluation of forest insect infestations. Annual Review of Entomology 12:207-228.

An examination of several methods of evaluating forest insect infestation. Sampling methodology and design are discussed for population trends and distribution studies.

112. Kuchler, A. W. 1967. Vegetation Mapping. Ronald Press Co., New York. 472 pp.

A description of the potential plant communities of the United States. Field techniques, aerial photographic interpretation, and several methods of vegetation mapping and classification are presented.

113. Langley, R. 1970. Practical Statistics Simply Explained, revised ed. Dover Publications, New York. 399 pp.

As the title implies, this book is an eminently readable, clear introduction to statistics. Of particular value for designing baseline studies are the sections on sampling and design of investigations.

114. Leopold, Luna B., M. Gordon Wolman, and John P. Miller. 1964. Fluvial Processes in Geomorphology. W. H. Freeman and Co., San Francisco. 522 pp.

A comprehensive discussion of the forces and factors that combine to fashion the physical habitats of running waters.

115. Lewis, R. A., E. M. Preston, and N. R. Glass. 1977. The Biological Effects of Air Pollution from Fossil Fuel Burning Power Plants in the North Central Great Plains. In Proceedings, 70th Annual Meeting, Air Pollution Control Association, Toronto.

Report summarizes a conceptually well developed program for developing a predictive methodology to assess the ecological impacts of coal-fired power plants on short-grass ecosystems. It is one of the few current projects directly aimed at advancing the state of the art of impact assessment. Although the overall program is conceptually sound, not all of the individual tasks are being conducted up to the same standard. A brief list of references at the end of the paper provides access to more detail on this unique and promising program.

116. Linder, R. L., and C. N. Hillman, eds. 1973. Proceedings of the Black-Footed Ferret and Prairie Dog Workshop. South Dakota State University, Brookings.

Papers presented at the workshop focus primarily on past and present status and distributions of the black-footed ferret and prairie dog. Viewpoints on management and research needs for these two species are also expressed.

117. Linhart, S. B., and F. F. Knowlton. 1973. Determination of Relative Carnivore Densities in Western United States. Annual meeting of the American Society of Mammalogists 63. 9 pp. transcript.

Describes the standardization of the scent-station technique to obtain indices of relative abundance of predators in 17 western states. Their purposes are to: indicate local and regional year-to-year changes in abundance; indicate current population status and distribution of certain predators, particularly the coyote; determine if correlations exist between coyote densities, control efforts, predation, and livestock husbandry practices; better understand relationships, assuming such exist, between relative densities of coyotes and those of other carnivores competing within the same ecosystem.

118. Linhart, S. B., and F. F. Knowlton. 1975. Determining the relative abundance of coyotes by scent station lines. Wildlife Society Bulletin 3(3):119-124.

A method utilizing scent-station transects for estimating relative abundance of coyotes is described. The method is now in use in 17 western states and does provide a reliable estimate of abundance. The method is applicable to all carnivores but will give only estimates of relative abundance.

119. Linsley, R. K., M. A. Kohler, and J. L. H. Paulhus. 1958. Hydrology for Engineers. McGraw-Hill Book Co., New York. 340 pp.

An excellent text on the basics of hydrology. As an engineering text, it provides a basic knowledge of quantitative problem-solving techniques applicable to surface water resources. It also provides information on collection and use of surface water data and associated statistical techniques.

120. Lord, Rexford D., Jr. 1959. Comparison of early morning and spotlight roadside censuses for cottontails. Journal of Wildlife Management 23(4):458-460.

A series of early morning and nighttime roadside censuses of cottontail rabbits was performed. Comparison of results indicates that greater numbers of rabbits are observed when the census is conducted at night, except during summer when more rabbits were counted during the morning census.

121. Lovaas, A. L., Joseph L. Egan, and Richard R. Knight. 1966. Aerial counting of two Montana elk herds. Journal of Wildlife Management 30(2):364-369.

This article reports the results of repeated aerial counts of wintering elk in two mountainous areas in Montana. The authors report high variability in the counts largely attributed to variations in weather, in elk distribution, and visibility due to snow cover and terrain features. The authors conclude that it is not practical to attempt to apply reliability limits or standards to the observations and that the aerial counts at best serve as a general index to broad population trends.

122. Loveless, Charles M. 1967. Ecological Characteristics of a Mule Deer Winter Range. Technical Publication No. 20, Colorado Game, Fish, and Parks Department. 125 pp.

The study attempts to characterize the major natural environmental factors such as weather, topography, vegetation distribution, and microenvironment, which affect mule deer on winter range, and to determine the response of mule deer to these factors. Provides basic information on the complex relationships between natural environmental factors and mule deer activity and distribution.

123. Lund, J. W. G., and L. F. Talling. 1957. Botanical limnology methods with special references to the algae. Botanical Review 23:489-583.

A review of methods and discussion of problems encountered in sampling and analyzing samples of phytoplankton and periphyton.

124. Mannette, L. T., and K. P. Haydock. 1963. The dry-weight-rank method for the botanical analysis of pasture. British Grassland Society 18:268-275.

Describes a technique for estimating the percent of total dry-weight biomass contributed by dominant plant species in a sampling area. The technique is based upon observer estimation and ranking of percent contribution by the three dominants in a number of sample plots. As such, its accuracy is limited by the level of expertise of the observer. However, when the observer is sufficiently well trained, the technique compares favorably with hand-separation clipping techniques. Technique provides an efficient means of obtaining percentage estimates but cannot give any absolute values of dary weight.

125. Marmelstein, Allan, (ed.). 1977. Classification, Inventory, and Analysis of Fish and Wildlife Habitat: A National Symposium. U.S. Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C.

The symposium provides a cross-section of recent developments in the classification and evaluation of upland, wetland, and aquatic habitats. Field studies, map interpretation, data compilation, data analysis, and data interpretation procedures are presented.

126. Martinson, R. K., and C. F. Kaczynski. 1967. Factors Influencing Waterfowl Counts on Aerial Surveys, 1961-66. Special Science Report: Wildlife No. 105. U.S. Fish and Wildlife Service. 78 pp.

Emphasizes the necessity for air-ground correction of aerial censuses of waterfowl. Recommendations are made for improving the accuracy of aerial counts.

127. Mason, C. E., and H. D. Blocker. 1973. A stabilized drop trap for unit area sampling of insects in short vegetation. Environmental Entomology 2(2):214-216.

The sampling device noted in the title samples a 0.5 m^2 area. Arthropods are removed from the trap with a vacuum collector. The trap works best in vegetation less than 50 centimeters tall.

128. Matthews, Robert W., and Janice R. Matthews. 1971. The malaise trap: its utility and potential for sampling insect populations. Michigan Entomologist 4(4):117-122.

Malaise traps as nonattractant samplers of insect populations offer an efficient and economical means for obtaining large quantities of data with minimal effort. Trap placement, relative collecting efficiency, and operational strengths and weaknesses are discussed in this paper.

129. McWhorter, D. B., and D. K. Sunada. 1977. Groundwater Hydrology and Hydraulics. Water Resources Publication, Fort Collins, Colorado. 350 pp.

Provides an excellent basis for quantitative analysis of aquifer hydraulics. Such topics as well design; the analysis of the effects of groundwater pumping on surface water, other wells, and aquifers; and the determination of hydraulic properties by aquifer testing are presented. Includes the associated theory and detailed mathematical treatment leading to the methodology required for analytical problem solving.

130. Meinzer, O. E. 1923. The Occurrence of Groundwater in the United States. U.S. Geological Survey Water Supply Paper 489. U.S. Government Printing Office, Washington, D.C. 321 pp.

This is the classic discussion of the basic principles of geo-hydrology. It also provides general information of the groundwater resources of the United States.

131. Mendenhall, W., L. Ott, and R. L. Scheaffer. 1971. Elementary Survey Sampling. Wadsworth Publishing Co., Belmont, California. 247 pp.

This introductory text covers design and analysis of sample surveys in business, social science, and natural resource management. Explanations are intuitive, and the general approach is practical.

132. Menhinick, Edward F. 1963. Estimation of insect population density in herbaceous vegetation with emphasis on removal sweeping. Ecology 44(3):617-621.

Three methods of estimating population density of insects were compared. Removal trapping using a sweep net proved to be most effective. Mark-and-recapture procedures proved to be unsatisfactory in the vegetation type sampled in this study. Number of sweeps required for removal trapping estimates varied depending on species of insect and weather conditions.

133. Mercer, Thomas T. 1973. Aerosol Technology in Hazard Evaluation. Academic Press, New York. 384 pp.

Portions of this book are quite technical and address subjects not directly related to baseline assessments of aerosols. However, much of the book deals with aerosol sampling, sizing and problems associated with these processes. It contains sections on aerosol properties, their sizes and size distributions and potential hazards. For those instances when concerns with aerosol pollutants are a factor, this book serves as a valuable reference.

134. Milner, C., and R. E. Hughes. 1968. Methods of Measurement of the Primary Production of Grassland. Blackwell Scientific Publications, Oxford and Edinburgh. 82 pp.

The text is divided into three parts: measurement of the primary production of grassland; measurement of the primary production of dwarf-shrub heaths; and measurement of the primary production of arid-zone communities. Methods of measurement are detailed for each section.

135. Morris, M. J. 1967. An Abstract Bibliography of Statistical Methods in Grassland Research. U.S. Department of Agriculture, Forest Service Miscellaneous Publication No. 1030. 222 pp.

This bibliography covers literature of the world through 1963. It was prepared for scientists concerned with problems of defining and measuring biotic parameters and of sampling populations in grassland communities.

136. Morse, M. A. 1943. Technique for reducing man-power in the deer drive census. Journal of Wildlife Management 7(2):217-220.

A combination deer drive and track count is recommended as a deer census method requiring less manpower than the standard deer drive census. Advantages include: reduced manpower, greater efficiency, simplification of techniques and, reduced preparation time. Disadvantages include: the census requires a fresh snowfall of 2 to 3 inches, the census is difficult in brushy areas and, wind reduces accuracy.

137. Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York. 547 pp.

One of the best current general plant ecology references, this text provides a summmary of vegetation sampling techniques and data analyses. Used in the United States and Europe. Techniques are provided for most vegetation types.

138. National Academy of Sciences. 1970. Remote Sensing with Special Reference to Agriculture and Forestry. National Academy of Sciences, Washington, D.C. 424 pp.

A development of concepts, value judgments, and background for potential uses of remote sensing in agriculture and forestry. Gives a technical appraisal of state-of-the-art sensors and discrimination techniques.

139. Natrella, M. G. 1963. Experimental Statistics. National Bureau of Standards, Handbook No. 91. U.S. Department of Commerce. pp. discontinuous.

Although designed for U.S. Army research, this is an excellent reference for a variety of statistical techniques. Techniques are presented with step-by-step instructions for attaining a stated goal. The book is geared to a practical approach.

140. Neff, Don J., O. C. Wallmo, and D. C. Morrison. 1965. A determination of defecation rate for elk. Journal of Wildlife Management 29(2): 406-407.

A 217-acre enclosure containing a known number of elk was subsampled with pellet count transects to derive defecation rates. Statistical analysis suggests the subsample is valid and calculation of pellet groups deposited per elk-use-day yields a rate of 12.52 ± 1.38 pellet groups daily.

141. Neff, Don J. 1968. The pellet-group count technique for big game trend, census, and distribution: a review. Journal of Wildlife Management 32:597-614.

The author assembles and reviews a mass of widely scattered information concerning the pellet-group count technique for big game trend, census, and distribution studies. The review discusses general principles that should be applied in using the technique (based on field results) and problems often encountered in field application. The bibliography contained in this article provides access to literature dealing with specific aspects and applications of the pellet-group-count technique.

142. Nelson, R. D., I. O. Buss, and G. A. Baines. 1962. Daily and seasonal crowing frequency of ring-necked pheasants. Journal of Wildlife Management 26(3):269-272.

This article reports on investigations aimed at determining the time of year and time of day when pheasant crowing reaches maximum intensity, and degree of individual variation in crowing. The authors summarize observations made on captive pheasants during two years. Seasonal and diurnal crowing patterns are graphed and statistically evaluated.

143. Newman, D. E. 1959. Factors influencing the winter roadside count of cottontails. Journal of Wildlife Management 23(3):290-294.

Data obtained from roadside counts were analyzed to determine the effects of time of day and weather on census results. Cottontail activity decreases with increasing light during morning counts and increases with decreasing light during evening counts. Adjustment formulae were given for estimating rabbit number from data obtained during periods of snow cover.

144. Noll, Kenneth E., and Terry L. Miller. 1977. Air Monitoring Survey Design. Ann Arbor Science, Ann Arbor, Michigan. 287 pp.

The objective of this book is to present the information necessary to establish a comprehensive air-monitoring program. In addition to addressing the subjects of equipment selection, calibration and operation, the book presents information on the selection of monitoring sites, the integration of air and meteorological monitoring programs, and the establishment of a quality-assurance program. The final sections of the book address data processing, analysis and evaluation. A very valuable publication for anyone charged with establishing an air-quality-monitoring program.

145. Odum, Eugene P., and J. L. Cooley. 1976. Ecosystem Profile Analysis and Performance Curves as Tools for Assessing Environmental Impact. The Institute of Ecology, University of Georgia, Athens. 25 pp.

A unique viewpoint suggesting that impact assessments must evolve from component analysis to more holistic approaches is stated. Suggests use of integrative measurements as indices of whole-system performance. Paper also goes into graphs of component and ecosystem properties plotted against each other in ecosystem profiles and graphs of ecosystem characteristics, such as diversity, against intensity of disturbance to provide "performance curves". Applications of the concepts presented are not well developed.

146. Odum, Eugene P. 1977. The emergence of ecology as a new integrative discipline. Science 195(4284):1289-1293.

In providing a useful perspective on linking theoretical ecology with the needs of environmental decisonmaking, this paper stresses the need to combine a holistic viewpoint (wherein new properties, not evident at lower levels of organization, emerge) with reductionism (more detailed studies of smaller and smaller components). The paper suggests that most impact statements focus on the species or factor level when questions and decisions clearly involve the ecosystem level. A general approach to resolving the problems is provided, but details are lacking.

147. Oosting, H. J. 1956. The Study of Plant Communities: An Introduction to Plant Ecology. W. H. Freeman, San Francisco. 440 pp.

Methods and rationale for plant community studies. The text is one of the classics of plant ecology.

148. Ostle, B., and R. W. Mensing. 1975. Statistics in Research, 3rd ed. Iowa State University Press, Ames. 596 pp.

This is an unusually comprehensive reference on applied statistics. In addition to providing methods and examples, it pays particular attention to the assumptions underlying the techniques presented. Some knowledge of statistics is required to use it.

149. Overton, W. S. 1971. Estimating the numbers of animals in wildlife populations, pp. 403-456. In R. H. Giles, (ed.), Wildlife Management Techniques, 3rd ed. The Wildlife Society, Washington, D. C. 633 pp.

This chapter of the techniques manual surveys the literature for techniques of estimating wildlife populations. Techniques are provided for mammal and bird population estimates. Design assumptions for statistical analysis are included. The text is one of the best single references for field studies and data analyses of game mammals and birds.

150. Parkinson, D., T. R. G. Gray, and S. T. Williams. 1971. Methods for Studying the Ecology of Soil Micro-Organisms. International Biological Program Handbook Number 19. Blackwell Scientific Publications, Oxford.

A compilation of techniques to isolate and enumerate soil microorganisms. Some highly specialized and new approaches to soil problems are presented.

151. Perkins, R. J. 1974. Stress and its relation to the ecosystem. International Journal of Ecology and Environmental Sciences 1:119-128.

A promising approach to impact assessment at the ecosystem level. Proposes an index that quantifies functional as well as structural changes as a measurement of environmental quality and demonstrates application of the index to eight different ecosystems in an attempt to measure overall impacts and effectiveness of mitigation measures.

152. Petersen, L. E., and A. H. Richardson. 1975. The Wild Turkey in the Black Hills. Bulletin No. 6. South Dakota Department of Game, Fish, and Parks, Pierre, South Dakota.

Life history and ecology of the wild turkey. Includes studies on food habits, brood size, habitat requirements and management techniques.

153. Petrusewicz, K., and A. MacFayden. 1970. Productivity of Terrestrial Animals - Principles and Methods. International Biological Program Handbook 13. F. A. Davis Co.

This text describes techniques for conducting small mammal productivity studies. It is a valuable aid in designing population studies and in interpreting results.

154. Phillips, J. M., and D. S. Hayman. 1970. Improved procedures for clearing roots and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Transaction of the British Mycological Society 55:158.

Two procedures are presented that improve stain penetration and clearing in whole mycorrhizal roots of onion and other host plants, and in roots infected by other fungi. The procedures were utilized for estimating the amount of mycorrhizal infection in the root cortex. Estimates were difficult using more standard staining procedures because internal hyphae, arbuscules, and vesicles were not well defined.

155. Phillipson, J. 1970. Methods of Study in Soil Ecology. Proceedings of the Paris Symposium. UNESCO Publications.

A collection of papers from a UNESCO/IBP symposium in Paris. The papers cover a wide range of subjects but follow a common theme of presenting new methods and techniques for the study of production and energy flow in soil systems.

156. Pielou, E. C. 1977. Mathematical Ecology. John Wiley and Sons, New York. 385 pp.

Particularly good for the statistical study of populations and communities and for quantitative descriptive ecology. It is quite theoretical, however, and it requires a good mathematical background. It discusses population dynamics, spatial patterns, measurement of ecological diversity, the classification of communities, and other related topics.

157. Poelker, R. J., and H. S. Hartwell. 1973. Black Bear of Washington. Washington Game Department, Biology Bulletin 14. Olympia, Washington. 180 pp.

The purpose of this bulletin is two-fold: to provide information on the problem of black bear damage to coniferous forests and to provide data on the natural history of black bear populations. Basic information on reproduction, physical characteristics, food habits, population characteristics, and disease is included. Methods for ear tagging and placement of radio-collared transmitters are also given.

158. Poole, R. W. 1974. An Introduction to Quantitative Ecology. McGraw-Hill, New York. 532 pp.

This excellent introductory reference stresses actual use of quantitative methods on actual field data and provides a balanced treatment of plant and animal ecology. It is written for nonmathematically inclined biologists with only a high-school-algebra background. It develops concepts of modeling from an intuitive approach and provides methods immediately applicable to design, implementation, and analysis of ecological baseline studies.

159. Porter, David K. 1974. Accuracy in Censusing Breeding Passerines on the Shortgrass Prairie. U.S. International Biological Program, Grassland Biome Technical Report No. 5. Natural REsource Ecology Laboratory, Colorado State University, Fort Collins. 108 pp.

Census methods in estimating breeding populations of five species of birds on the shortgrass prairie are compared for accuracy. Methods used include spot-mapping, flushing, total count, roadside count, and Emlen strip count procedures. Factors affecting the accuracy of the mapping method are analyzed. The factors tested are width of the census strip, speed of traverse, time of day, observer variation, weather and species effectivity.

160. Postupalsky, Sergej. 1974. Raptor reproductive success: some problems with methods, criteria, and terminology, pp. 21-31. In Management of Raptors, Proceedings of the Conference on Raptor Conservation Techniques, held March 22-24, 1973. Fort Collins, Colorado.

Review of purposes, methodologies, and experimental-design considerations for determining reproductive success within raptor populations. Also defines standard terminology used in raptor studies.

161. Progulske, Donald R., and Donald C. Duerre. 1964. Factors influencing spotlighting counts of deer. Journal of Wildlife Management 28(1): 27-34.

White-tailed and mule deer were censused in meadows at night through the aid of a spotlight. Herd composition, availability of foods in meadows, type and size of meadow, hour of observation, and several meteorological factors influenced nightly counts.

162. Reed, Rodman C. 1972. Insects and Other Major Arthropods of a Tallgrass Prairie. Technical Report No. 166. Grassland Biome, U.S. International Biological Program. 144 pp.

Arthropod population studies were conducted in the tallgrass prairie. Sampling enclosures, vacuum collector, sweep netting, pitfall trap, and Berlese funnel sampling methods are described.

163. Ricker, William E. 1968. Methods for Assessment of Fish Production in Fresh Water. International Biological Program, Handbook No. 3. Blackwell Scientific Publications, Oxford and Edinburgh. 313 pp.

Methods for capturing freshwater fishes and analyzing catches in terms of biomass and population dynamics.

164. Rickert, David A., Walter G. Hynes, and Stuart W. McKenzie. 1976. Methodology for River-Quality Assessment with Application to the Willamette River Basin, Oregon. Circular 715-M. U.S. Geological Survey, Washington, D. C. 55 pp.

This report is an excellent example of a river basin study that was undertaken to accomplish specific goals. Parameters to be studied were carefully selected prior to field work so that only the most meaningful data were collected. Results are amenable to statistical analysis. Effective use of mathematical models is exemplified. The study emphasizes the development of approaches, methods, and data programs that would be useful in assessing environmental conditions in other river basins.

165. Robbins, Chandler S., and W. T. Van Velzen. 1969. The Breeding Bird Survey, 1967 and 1968. Special Science Report - Wildlife No. 124 U.S. Bureau of Sport Fisheries and Wildlife, Washington, D. C. 107 pp.

A breeding bird census was utilized to compare relative abundance of birds across North America. The paper presents methods utilized and analysis of population trends.

166. Robel, Robert J. 1960. Determining elk movements through periodic aerial counts. Journal of Wildlife Management 24(1):103-104.

The article reports on the use of sequential aerial surveys during fall-through-spring months to determine migratory patterns of elk in the Selway district of Idaho. Mapped percentages of elk observation through the area compare favorably with concurrent ground-observation results, suggesting that the aerial technique is useful.

167. Robinette, W. L., C. M. Loveless, and D. A. Jones. 1974. Field tests of strip census methods. Journal of Wildlife Management 38(1):81-96.

Strip censuses based on perpendicular-distance sighting of a known population were converted to population estimates according to 10 different strip-census methods. The results obtained were compared to the known population size, and the most accurate methods are identified. The article discusses the merits and drawbacks of the various methods and gives a good discussion of the sources of potential error in each.

168. Rose, R. E., and J. G. Miller. 1954. Some sampling variations in soil fungal members. Journal of General Microbiology 10:1-10.

Errors resulting from direct plate fungal counts are more likely a result of variation between cores collected in the field than of subsampling and plating methods in the laboratory. Recommendations are made with regard to the number of field and laboratory samples necessary to reduce errors in counts resulting from variation between samples.

169. Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. Agriculture Handbook No. 60. U.S. Department of Agriculture. 160 pp.

Field and laboratory analyses for saline and alkali soils are described and analyses of data discussed. Saline and alkali soil-plant relationships are described. Analytical techniques for saline or alkali irrigation water are included.

170. Sanderson, Glen C., and Helen C. Schultz. 1973. Wild Turkey Management: Current Problems and Programs. University of Missouri Press, Columbia. 355 pp.

This book discusses the ecology of the wild turkey. Field study methods, data analyses and data interpretation for turkey population studies are included.

171. Sargeant, A. B., W. K. Pfeifer, and S. H. Allen. 1975. A spring aerial census of red foxes in North Dakota. Journal of Wildlife Management 39(1):30-39.

Describes the use of aerial transects for locating red fox families as a means of determining population density. The technique is most useful in flat, relatively unvaried, sparsely vegetated areas. The article also presents the results of a study that utilized the technique on six townships in eastern North Dakota.

172. Sauder, D. W., R. L. Linder, R. B. Dahlgren, and W. L. Tucker. 1971. An evaluation of the roadside technique for censusing breeding waterfowl. Journal of Wildlife Management 35(3):538-543.

This report discusses investigations in South Dakota aimed at determining the number of replicate counts of a roadside transect needed to establish a statistically sound population index of breeding waterfowl and to analyze the influence of wind, light intensity, vegetative phenology, and wetland size on counts. The number of replicates required was less when the index was based on number of wetlands instead of transect miles.

173. Schultz, V. 1961. An Annotated Bibliography on the Uses of Statistics in Ecology - a Search of 31 Periodicals. Publication TID-3908. U.S. Atomic Energy Commission, Office of Technical Information, Environmental Science Branch, Division of Biology and Medicine, Washington, D.C. 314 pp.

Summarizes the applications of statistics in ecology as reported in 31 serial publications from their first issues through 1958. Fields included are: wildlife, fisheries science, limnology, oceanography, plants and insects.

174. Schultz, V., L. L. Eberhardt, J. M. Thomas, and M. I. Cochran. 1976. A Bibliography of Quantitative Ecology. Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania. 361 pp.

Summarizes a search of major periodicals from first issues through 1974, concentrating on uses of mathematics and statistics in ecology. A partial listing of subjects includes: cycles, diversity, energetics and productivity, growth of populations, ordination, patterns, plotless sampling, plots and quadrats, population estimation, sampling, and mathematical, population, stochastic, and compartment models.

175. Scott, Thomas G., (ed.). 1963. Grouse management symposium. Journal of Wildlife Management 27(4):525-887.

The symposium presented a diverse collection of population-ecology papers on North American getraonidae. Species discussed included blue, spruce, ruffed, sharp-tailed, and sage grouse, ptarmigan, and prairie chickens. Individual papers discuss sampling methodologies and analytical and interpretive techniques for evaluation of habitat preference, population density, sex ratios, food habits, predator-prey interactions, Tetraonid diseases, and a history of introductions in North America.

176. Scott, V. W., and E. L. Boeker. 1972. An evaluation of wild turkey call counts in Arizona. Journal of Wildlife Management 36(2):628-630.

This investigation was undertaken to evaluate the utility of gobbler call-count road transects as a population index for Merriam's wild turkey in Arizona. Six years of call counts are reported. The authors evaluate sex-ratio effects on calling and analyze replicate count results for correlations with other factors such as poult production, weather, and sex ratio. Possible complications relative to the use of gobbler call counts as a population index are presented.

177. Seber, G. A. F. 1973. The Estimation of Animal Abundance. Hafner Press, New York. 506 pp.

This is an excellent text for designing studies of faunal populations. A good cross-section of the literature concerning population abundance estimates is discussed. Examples of population studies are provided for a broad range of faunal species. Methods and design assumptions are discussed for most of the commonly used census techniques. Statistical analyses are presented in detail.

178. Sharma, Rajendra K., John D. Buffington, and James T. McFadden, (eds.). 1975. Proceedings of the Nuclear Regulatory Commission Workshop on the Biological Significance of Environmental Impacts. U.S. Nuclear Regulatory Commission, Washington, D.C. 327 pp.

This is a most useful collection of papers on recent thinking about environmental assessments. It deals with general perspectives on impact assessment and then focuses on impacts originating in both terrestrial and aquatic systems, emphasizing the importance of (and problems in) providing statistical bases for impact evaluations. While the philosophy expressed is excellent, details on applying the philosophy are not extensive.

179. Simon, C. A. 1975. The Influence of Food Abundance on Territory Size in the Iguanid Lizard Sceloporusjarrovi. Ecology 56:993-998.

This reports a study to determine how food abundance affects territory size for the insectivorous Sceloporus jarrovi. Territories are defined as defended areas, and the converpolygon method is used to determine territorial boundaries. Natural-food abundance is inversely correlated with territory size. Summer territories compressed significantly when food was added, even though natural food supplies seemed adequate.

180. Simpson, G. G., A. Roe, and R. C. Lewontin. 1960. Quantitative Zoology. Harcourt, Brace & World, New York. 440 pp.

One of the classic books in applying statistics to zoology. As such, it is better suited to laboratory studies than baseline studies, but it covers the application of statistics to a broad range of biological topics and requires only a minimal mathematical background.

181. Singh, J. S., W. K. Lauenroth, and R. K. Steinhorst. 1975. Review and assessment of various techniques for estimating net aerial primary production in grasslands from harvest data. Botanical Review 41(2): 181-222.

Critical review of thirteen different methods for estimating above-ground productivity. Compares various methods and picks five "best" estimates, relative to ease of application and adequacy of estimates obtained. Includes consideration of statistical and experimental-design requirements.

182. Singleton, P. C., and A. J. Cline. 1976. Detailed Soil Survey Basic to Sound Rehabilitation Planning. Science Monograph No. 35. Agricultural Experiment Station, University of Wyoming, Laramie. 27 pp.

The paper describes the use of soil-survey information and laboratory analyses in evaluating soils capabilities and in making reclamation recommendations. Twelve laboratory analyses are recommended for soils that are to be rehabilitated.

183. Sisson, Leonard. 1976. The Sharp-Tailed Grouse in Nebraska. Nebraska Game and Parks Commission, Lincoln, Nebraska. 88 pp.

Population studies were conducted on sharp-tailed grouse in Nebraska. Breeding birds were estimated using listening counts and dancing ground counts. Line transects were used to locate nests and estimate number of broods. Habitat requirements and population ecology are discussed.

184. Sittig, Marshall. 1974. Pollution Detection and Monitoring Handbook. Noyes Data Corporation, Noyes Building, Park Ridge, New Jersey. 400 pp.

The author first presents a brief section on air pollutants and general monitoring procedures. He presents the various types of existing analytical systems compares them, and presents criteria that a user should consider in selecting a system. The second section of the book is a presentation of monitoring techniques, with original source references, for a multitude of atmospheric pollutants. The sections for each pollutant each contain a brief introduction to its sources, toxicity, and environmental significance followed by techniques for its measurements.

185. Sladeckova, A. 1962. Limnological investigation methods for the periphyton (aufwuchs) community. Botanical Review 28:286-350.

Comprehensive review of methods for sampling periphyton on natural and artificial substrata.

186. Smith, Arthur D. 1964. Defecation rates of mule deer. Journal of Wildlife Management 28(3):435-444.

This article provides a discussion of the variability in pellet-group defecation rates of mule deer. The age of the animal, amount and type of forage eaten, affected the rate of defecation. Deer in pens and in the field were studied during the four seasons.

187. Smith, Ronald H. 1968. A comparison of several sizes of circular plots for estimating deer pellet group density. Journal of Wildlife Management 32(3):585-591.

The literature concerning pellet-group counts and plot size is reviewed and compared with results from a study on the North Kaibab. Sampling efficiency and accuracy of counts are evaluated in relation to plot size. Generally, sampling efficiency and pellet group densities decreased as plot size increased.

188. Snedecor, G. W., and W. G. Cochran. 1967. Statistical Methods, 6th ed. Iowa State University Press, Ames. 593 pp.

This classical statistics text serves as a reference for a broad spectrum of statistical techniques.

189. Soil Conservation Service. 1967. Soil Survey Laboratory Methods and Procedures for Collecting Soil Samples. Soil Survey Investigations Report No. 1. U.S. Government Printing Office, Washington, D.C.

The report describes laboratory methods and procedures used in soil survey laboratories of the soil conservation service. Methods for collecting, preparing, and analyzing samples for physical and chemical studies of soils are included.

190. Soil Conservation Service. 1972. National Engineering Handbook, Section 4, Hydrology. U.S. Government Printing Office, Washington, D.C. pp. discontinuous.

A widely used guideline for actual analysis of small-watershed characteristics. Provides flood hydrograph calculation techniques based upon basin landuse and vegetation characteristics, soil types, and rainfall/snow melt runoff. Watershed yield determination is also discussed.

191. Soil Conservation Service. 1976. National Range Handbook. U.S. Department of Agriculture, Washington, D. C. pp. discontinuous.

The handbook deals with the study, inventory, analysis, treatment, and management of the natural resources composing native grazing land ecosystems. It utilizes an interdisciplinary approach to planning and implementing resource conservation programs. Methodologies useful for resource appraisals and inventories are provided. The manual is primarily intended for use by the SCS but has broad applications for resource conservation programs.

192. Soil Survey Staff. 1951. Soil Survey Manual. U.S. Department of Agriculture Handbook 18. U.S. Government Printing Office, Washington, D. C.

This manual describes methods for classifying and mapping soils. Procedures for field sampling, data recording, data summarizing, map classifying and interpreting are included. This manual was updated by a supplement in 1962.

193. Soil Survey Staff. 1960. Soil Classification, A Comprehensive System - 7th Approximation. U.S. Department of Agriculture, U.S. Government Printing Office, Washington, D. C.

Describes the procedures for classifying and naming soil types. The manual was updated by a supplement in 1967.

194. Soil Survey Staff. 1962. Supplement to USDA Handbook 18, Soil Survey Manual. U.S. Department of Agriculture, U.S. Government Printing Office, Washington, D. C.

This handbook supplements the soils classification and mapping procedures manual of 1951.

195. Soil Survey Staff. 1967. Supplement to Soil Classification, A Comprehensive System - 7th Approximation. U.S. Department of Agriculture, U.S. Government Printing Office, Washington, D. C.

Supplements the soil classification manual of 1960. Procedures are presented for classifying and naming soils.

196. Soil Survey Staff. 1975. Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Agricultural Handbook 436. Soil Conservation Service, U.S. Government Printing Office, Washington, D. C. 754 pp.

This text gives the present status of the taxonomy being used to make and interpret soil maps in the United States. It defines the categories and classes and gives data and descriptions for selected soils. The first six chapters present general principles and concepts of soil classification and give cross references for definitions of selected criteria. Later chapters discuss the classification of specific soil orders.

197. Sokal, R. R., and F. J. Rohlf. 1969. Biometry: The Principles and Practice of Statistics in Biological Research. W. H. Freeman & Co., San Francisco. 776 pp.

This is an excellent basic reference on the use of statistics in biological investigations. The most important topics treated are the simple distributions (binomial, Poisson, and normal), simple statistical tests, analysis of variance through factorial analysis, analysis of frequencies, regression, and correlation. A "cookbook" approach is used with emphasis on computational techniques. Of particular value is a keyed tabular guide to statistical methods according to study objectives.

198. Southwood, T. R. E. 1966. Ecological Methods, With Particular Reference to the Study of Insect Populations. Metheun, London. 391 pp.

A discussion of field methods and data analyses for studies of insect populations. Marking techniques, unit-area sampling, relative-abundance-study methods, and population analyses are discussed. This is a good general reference for ecological studies of insects.

199. Spurr, S. H., and B. V. Barnes. 1973. Forest Ecology. Ronald Press, New York.

This text deals with the ecological basis for managing forested land. Discussions of diversity between and within species, autecology, synecology, and phytogeography are provided as four major subdivisions. The discussions are useful in interpreting existing ecological conditions and evaluating the potential changes in forest communities.

200. Stalnaker, C. B., and J. L. Arnette, (eds.). 1976. Methodologies for the Determination of Stream Flow Requirements: An Assessment. U.S. Fish and Wildlife Service, Office of Biological Services, Western Water Allocation, Logan, Utah. 199 pp.

An exceptionally well-presented collection of papers that discuss "state-of-the-art" methodologies for assessing streamflow characteristics and impacts of flow alteration on ecological systems. Methods involve mathematical and statistical analysis of experimental data, thus enabling quantification of environmental factors and relationships. Considerable attention is given to modelling and its utility in evaluating impacts and in assessing interactions among ecosystem components.

201. Stebbins, R. C. 1966. A Field Guide to Western Reptiles and Amphibians. Riverside Press, Cambridge. 279 pp.

A good general field guide to the reptiles and amphibians of western North America. General information on conducting field investigations and making captures is also provided.

202. Stewart, Robert E., and Harold A. Kantrud. 1972. Population estimates of breeding birds in North Dakota. Auk 89:766-788.

The primary strength of this paper is in its applying appropriate statistical methodologies to estimating breeding bird populations in North Dakota. Random sampling techniques permit statistical analysis of the results. Statewide population estimates obtained in the study provide a basis for comparison with future populations in areas facing increased human impact.

203. Strickland, J. D. H. 1960. Measuring the production of marine phytoplankton. Bulletin of the Fisheries Research Board of Canada 122: 1-172.

Complete description of methods for sampling and analyzing samples of phytoplankton. Most sections are applicable to freshwater phytoplankton as well as to marine phytoplankton.

204. Svensson, S. 1970. An international standard for mapping method in bird census work recommended by the International Bird Census Committee. Audubon Field Notes 24(6):722-726.

Introduces international standards for conducting a bird census using the mapping method. All aspects of methodology, data collection, evaluation, and applicability are presented. The census method can normally be used only for censusing the stationary part of noncolonial passerine and passerine-like bird populations during the breeding season.

205. Swope, H. M. 1967. The pheasant crowing count census and factors affecting its reliability. Colorado Department of Natural Resources, Division of Game, Fish and Parks, Game Information Leaflet No. 56. Colorado Division of Game, Fish and Parks, Denver. 3 pp.

Methods for conducting crowing cock pheasant counts are presented. Factors influencing counts include time in breeding season, daily crowing activity, sex ratio, weather, listening interference, and human error.

206. Thilenius, John F. 1972. Classification of Deer Habitat in the Ponderosa Pine Forest of the Black Hills, South Dakota. Forest Service Research Paper RM-91. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 28 pp.

Results of a study aimed at classifying deer habitat within a Ponderosa Pine forest. A sophisticated computer analysis of 334 attributes of vegetation, soil and site was used to distinguish 13 unique "habitat types" within what is often considered a single relatively homogenous habitat type. The results of the analysis provide an example of a high degree of resolution in habitat classification. However, time and dollar requirements are high, so the technique described would only be useful to baseline programs for very large projects.

207. Tinkle, D. W., and N. F. Hadley. 1975. Lizard reproductive effort: calorie estimates and comments on its evolution. Ecology 56:427-434.

The energy content of eggs of 10 lizard species was determined and used as a measure of reproductive effort (ratio of clutch calories to body calories). Correlation analysis was conducted for this measure of reproductive effort and for several measures of demographic variables.

208. Todd, D. N. 1960. Ground Water Hydrology. John Wiley and Sons, Inc., New York. 336 pp.

A basic text on groundwater resources. It provides an excellent introduction into the hydraulics of groundwater. Topics such as water-level fluctuation, basin-wide groundwater development, artificial recharge, salt water intrusion, legal aspects of groundwater development, and model studies are discussed at a general level of detail.

209. Tuite, J. 1969. Plant Pathological Methods, Fungi and Bacteria. Burgess Publishing Co., Minneapolis.

A broad-scale survey of microbiological techniques and their application to plant pathology. Several sections develop the concept and nature of plant disease. Detailed formulae are presented for a wide variety of selective growth media.

210. Turnbull, A. L., and C. F. Nicholls. 1966. A "quick trap" for area sampling of arthropods in grassland communities. Journal of Economic Entomology 59:1100-1104.

A spring-operated trap for area sampling of arthropods in grass communities is described. The trap is designed to drop on the area to be sampled when triggered from a distance. The trap avoids the danger of disturbing and driving away arthropods from the sampling area. The arthropods are removed by a vacuum collector. The method is compared with other sampling methods.

211. Turner, F. B. 1962. The demography of frogs and toads. Quarterly Review of Biology 37:303-314.

Quantitative studies of natality, mortality, and age distributions of anuran populations are reviewed. Specific problems are identified with respect to life history estimates of the age of individuals, age-specific fertility, natality of populations, larval survival, and age-specific postmetamorphic survival.

212. U.S. Bureau of Reclamation. 1974. Water Measurement Manual, 2nd. ed. U.S. Government Printing Office, Washington, D. C. 327 pp.

Provides excellent information on the selection, design, installation and calibration of facilities for collecting quantitative data on stream flow. Topics covered include weirs, flumes, orifices, flow measurement in open channels, and pressure conduits. Stream flow velocity and stage measuring techniques are discussed along with data-transmission techniques.

213. U.S. Fish and Wildlife Service. 1976. Habitat Evaluation Procedures. Division of Ecological Services. U.S. Fish and Wildlife Service. 26 pp.

The procedures noted in the title were developed for evaluating and comparing sites proposed for water and related land development projects. Both environmental and economic factors are considered through use of a non-monetary system employing habitat units and an economic (monetary) evaluation based on man-days. USFWS is expanding and refining the system to extend its applicability to all parts of the United States and to other project types.

214. U.S. Fish and Wildlife Service and Canadian Wildlife Service. 1977. Standard Operating Procedures for Aerial Waterfowl Breeding Ground Population and Habitat Surveys. U.S. Fish and Wildlife Service, U.S. Department of the Interior.

A new procedures manual for conducting waterfowl breeding population surveys and waterfowl production surveys. Field methods, such as survey time, dates, flight speed and altitude, and data collection are described in great detail.

215. Van Etten, Robert C., and Carl L. Bennett, Jr. 1965. Some sources of error in using pellet-group counts for censusing deer. Journal of Wildlife Management 29(4):723-729.

Errors made by observers in conducting pellet-group counts are discussed. Two of the most common errors included missing groups and calling new groups old.

216. Vollenweider, Richard A. 1974. Primary Production in Aquatic Environments. International Biological Program Handbook No. 12. Blackwell Scientific Publications, Oxford and Edinburgh. 225 pp.

Methods of collecting phytoplankton, periphyton, and macrophytes, and of analyzing samples in the laboratory.

217. Wallestad, Richard, and P. Schladweiler. 1974. Breeding season movements and habitat selection of male sage grouse. Journal of Wildlife Management 38(4):634-637.

Radio-telemetry studies of sage grouse cocks during the breeding season were conducted for two years in central Montana. The article identifies habitats frequented and total range of movement about a strutting ground. Sagebrush canopy cover in preferred feeding and loafing habitat was evaluated and recommendations are made for sagebrush removal projects near strutting grounds.

218. Wallestad, Richard. 1975. Life History and Habitat Requirements of Sage Grouse in Central Montana. Game Management Division. Montana Department of Fish and Game. 66 pp.

The dependence of sage grouse on sagebrush is explained in some detail. Field studies on population size and habitat preference included aerial and ground counts and tagging individuals. Crop analyses showed seasonal food preferences. Mortality rates, brood sizes, and nesting success are discussed, as are the effects of chemical treatment of sagebrush on the value of habitat for sage grouse.

219. Walsh, Leo M., and James D. Beaton. 1973. Soil testing and plant analysis. Soil Science Society of America, Madison, Wisconsin. 491 pp.

Discusses soil-sampling-design criteria, laboratory testing, data analyses and data interpretation. Many of the tests and analyses are designed for evaluating fertilizer requirements of cultivated crops.

220. Weatherly, A. H. 1972. Growth and Ecology of Fish Populations. Academic Press, London and New York. 293 pp.

Discusses factors affecting the growth and ecology of fish populations.

221. Weber, Cornelius I. 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. EPA-670/4-73-001. U.S. Environmental Protection Agency, Cincinnati, Ohio. pp. discontinuous.

Presents field methods for sampling and analyzing samples of plankton, periphyton, macrophytes, macroinvertebrates, and fish - with notes on biometrics and bioassay.

222. Weber, David A. 1975. Blue Grouse Ecology, Habitat Requirements, and Reponse to Habitat Manipulation in North Central Utah. Special Report No. 33. Utah Cooperative Wildlife Research Unit, U. S. Department of Agriculture, Forest Service, Region 4. 66 pp.

A fairly intensive baseline-type study of blue grouse was conducted on a study area in Cache County scheduled for herbicide application. Territory and call counts were conducted on foot and horseback and observations were compiled to yield evaluations of population distribution, habitat and food preferences, and other life-history information. Vegetation transects were also sampled to record the changes in vegetation after herbicide application. Alteration of blue grouse habitat in the herbicide-treated area was evaluated.

223. Weiner, James G., and Michael H. Smith. 1972. Relative efficiencies of four small mammal traps. Journal of Mammalogy 53:868-873.

This article compares the relative efficiencies of four types of small mammal traps: the small Sherman live trap, the Museum Special snap trap, the Victor mouse snap trap, and the Victor rat snap trap.

224. Welch, H. William, and Gordon D. Lewis. 1976. Assessing environmental impacts of multiple use land management. Journal of Environmental Management 4:197-209.

This paper provides a very useful systematic (matrix) approach to assessing potential effects of alternative land uses, which allows the simultaneous consideration of relationships among various land uses, the institutions that influence or control those uses, and the ecological and environmental systems with which those uses interact. The approach is valuable to decisionmakers in identifying inputs needed for assessing and highlighting those areas where knowledge is lacking.

225. Welch, Paul S. 1948. Limnological Methods. The Blakiston Co., Philadelphia. 381 pp.

This is the long-time standard reference on methods for limnological studies. Contains field and laboratory methods for examining lakes and streams and their major abiotic factors, and for collecting and processing plankton and macroinvertebrates.

226. Wielgolaski, F. E. 1975. Biological indicators of pollution. Urban Ecology 1(1):63-80.

This paper indicates some of the more useful biological indicators of pollution and reviews a number of criteria that must be evaluated in order to choose the best biological indicator for a study.

227. Wiens, John A. 1969. An Approach to the Study of Ecological Relationships Among Grassland Birds. Ornithological Monographs No. 8. The American Ornithologist's Union, Anchorage, Kentucky.

Presents a format for describing avian grassland habitats and describes the organization of the avian community of a Wisconsin grassland in terms of characteristics of habitats on the study area, territorial relationships, seasonal changes in habitat occupancy, utilization of habitats, and overt aggression between species. The paper's particular usefulness for baseline study is in its approach to defining which aspects of a habitat are important to which species; which must be components of a reestablished habitat; which must be retained in a disrupted habitat to enable the avifauna of an area to remain intact.

228. Wiens, John A. 1974. Climatic instability and the "ecological saturation" of bird communities in North American grasslands. The Condor 76(4): 385-400.

Population densities of bird communities were estimated by mapping individual territories using the "territory-flush" procedure. Once all territories are mapped, densities can be obtained by multiplying by a mating system conversion factor. Method is only applicable during the breeding season. An analysis of the structure of grassland avian communities is based on census information.

229. Wilber, H. M. 1975. The evolution and mathematical demography of the turtle *Chysemys picta*. Ecology 56:64-77.

A mark-recapture study of a population of painted turtles on the E.S. George Reserve in Livingston County, Michigan. Life tables are constructed and a demographic history of the population is suggested. A hypothetical population was simulated by recurrent use of a population-projection matrix to demonstrate the characteristics of stability in this species.

230. Wilde, S. A. 1958. Forest Soils: Their Properties and Relation to Silviculture. Ronald Press, New York.

Describes the factors influencing the development and characteristics of forest soils helpful in interpreting soils data from forest ecosystems.

231. Whitcamp, M. 1966. Decomposition of leaf litter in relation to environment, microflora, and microbial respiration. Ecology 47:194-201.

Bacterial and fungal counts, mycelial growth, microbial evolution of CO_2, and substrate moisture and temperature in bags were measured biweekly over a period of one year in oak, pine, and maple stands at Oak Ridge, Tennessee. All measurements were made at one elevation to exclude altitude and climate as variables and to allow analysis of seasonal and weather influences.

232. Wolfe, G. J. 1974. Siren-Elicited Howling Response as a Coyote Census Technique. Master of Science Thesis, Colorado State University, Fort Collins. 206 pp.

Describes the technique of estimating coyote density and distribution by enumerating howling responses elicited by an electronic police siren.

The effects of environmental variables on coyote response are discussed. The thesis also compares the adequacy of the siren-elicited howling response technique to intensive aerial surveys.

233. Wood, J. E. 1959. Relative estimates of fox populations. Journal of Wildlife Management 23(1):53-63.

The relative number of red and gray foxes was estimated in areas of the southeastern United States by a series of standardized trap lines placed along primitive roads. A scent-post method gave similar results to that of trapping. The census trap lines proved to be a satisfactory method of evaluating the effectiveness of predator control programs.

234. Zar, J. H. 1974. Biostatistical Analysis. Prentice-Hall, Englewood Cliffs, New Jersey.

A basic text and reference book on statistical analysis of biological data. Major topics are descriptive statistics; the normal, Poisson, and binomial distributions; and the testing of hypotheses concerning means, analysis of variance (through factorial analyses), regression and correlation (including multiple regression and correlation), and the analysis of frequencies. An outstanding set of statistical tables is included.

Figure 4-10 PERTURBATION MATRIX: ENE
AND RESULTING ENVIRONMEN

	ENVIRONMENTAL PERTURBATIONS	DEVELOPMENT ACTIVITIES						PRE-OPERATION ACTIVITIES													
		TEST DRILLING	TEST PIT EXCAVATION	SURVEYING	ROAD CONSTRUCTION	RIVER CROSSING CONSTRUCTION	TUNNEL CONSTRUCTION	OPERATION OF VEHICLES/MACHINERY	BLASTING	STRIPPING	GRADING	SURFACING/PAVING	DREDGING	FLOODING	IMPOUNDMENT	CHANNELIZATION	DEWATERING	LAND FILLING	FENCING	SURFACE	SUB
METEOROLOGICAL	CHANGE IN PRECIP. AMT./REL. HUMIDITY																				
	THERMAL EMISSIONS																				
	GASEOUS EMISSIONS																				
	PARTICULATE EMISSIONS																				
	OXIDANT EMISSIONS																				
	STEAM EMISSIONS																				
	RADIOACTIVE EMISSIONS																				
	TRACE ELEMENT EMISSIONS																				
	SALT DRIFT																				
	FUGITIVE DUST																				
	ODORS																				
	NOISE/VIBRATION																				
HYDROLOGICAL	GROUND H_2O DEPLETION																				
	SURFACE H_2O DEPLETION																				
	CHEMICAL DISCHARGE SURFACE H_2O																				
	THERMAL DISCHARGE SURFACE H_2O																				
	CHEMICAL DISCHARGE GROUND H_2O																				
	THERMAL DISCHARGE GROUND H_2O																				
	SURFACE H_2O FLOW SYSTEM ALTERATION																				
	GROUND H_2O FLOW SYSTEM ALTERATION																				
	SURFACE RUNOFF PATTERN CHANGE																				
	LEACHING																				
	SEDIMENTATION																				
	TURBIDITY																				
	MIXING OF STRATA (WATER BODIES)																				
	STREAM CHANNEL MODIFICATION																				

ION MATRIX: ENERGY DEVELOPMENT ACTIVITIES
TING ENVIRONMENTAL PERTURBATIONS.[1]

OPERATIONAL ACTIVITIES

TION ACTIVITIES

ING
POUNDMENT
CHANNELIZATION
DEWATERING
LAND FILLING
FENCING

SURFACE EXCAVATION
SUBSURFACE EXCAVATION
FUEL TRANSPORTATION
FUEL STORAGE
FUEL COMBUSTION
COOLING OPERATIONS
BY-PRODUCT REMOVAL
BY-PRODUCT STORAGE
BY-PRODUCT DISPOSAL
SANITARY WASTE TREATMENT
MAINTENANCE ACTIVITIES
TOPSOILING/REVEGETATION
IRRIGATION
FERTILIZER APPLICATION
CHEMICAL SPRAYS

OTHER ACTIVITIES

POST OPERATIONAL ACTIVITIES
TRANSIENT HUMAN ACTIVITIES
RECREATIONAL ACTIVITIES
HUNTING & FISHING

HYDROL	SEDIMENTATION
	TURBIDITY
	MIXING OF STRATA (WATER BODIES)
	STREAM CHANNEL MODIFICATION
TOPO-GRAPHIC	LANDSLIDES
	TOPOGRAPHY MODIFICATION
EDAPHIC	SOIL REMOVAL
	SOIL PROFILE MIXING
	SOIL TEMPERATURE CHANGE
	SOIL COMPOSITION CHANGE
	NUTRIENT CONTENT CHANGE
	SOIL PERMEABILITY CHANGE
	EROSION
GEOLOGIC	SUBSIDENCE
	SHRINK/SWELL CLAY EXPOSURE
	SEISMIC INSTABILITY
BIOLOGIC	VEGETATION REMOVAL
	CHANGE IN COMMUNITY TYPES
	CHANGES IN SPECIES COMPOSITION
	INTRODUCTION OF PLANT DISEASES/PESTS
	CHANGE IN NATURAL PHYSICAL SHELTERS
	DECREASED WATER SUPPLY
	CHANGE IN ANIMAL NUMBERS
	CHANGE IN ANIMAL SPECIES COMPOSITION
	INTRODUCTION OF DISEASES/PESTS
	BARRIER PLACEMENT
	WILDLIFE COLLISIONS
	WILDLIFE HARASSMENT
	IMPINGEMENT
	ENTRAINMENT
	FIRES

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[1] THE MATRIX IS USED AS A TOOL FOR IDENTIFYING THE ENVIRONMENTA FROM ENERGY DEVELOPMENT ACTIVITIES. BLANK SPACES HAVE BEEN IN BE ADDED AS NECESSARY.

IDENTIFYING THE ENVIRONMENTAL PERTURBATIONS RESULTING
TIES. BLANK SPACES HAVE BEEN INCLUDED SO CATEGORIES MAY

Figure 4-15 IMPAC
TAL PE
PROCE

ENVIRONMENTAL PERTURBATIONS

ECOSYSTEM COMPONENTS AND PROCESSES			METEROLOGICAL																			
FUNCTIONAL GROUP	COMPONENT	PROCESS	CHANGE PRECIP. AMT./REL. HUM.	THERMAL EMISSIONS	GASEOUS EMISSIONS	PARTICULATE EMISSIONS	OXIDANT EMISSIONS	STEAM EMISSIONS	RADIOACTIVE EMISSIONS	TRACE ELEMENT EMISSIONS	SALT DRIFT	FUGITIVE DUST	ODORS	NOISE/VIBRATION				GROUND H_2O DEPLETION	SURFACE H_2O DEPLETION	CHEM. DISCHARGE SURFA	THERMAL DISCHARG	CHEM. DISCH	THERM
DRIVING VARIABLES	ENERGY SOURCE																						
		RADIATION																					
		CONVECTION																					
		CONDUCTION																					
		RERADIATION																					
	H_2O SOURCE																						
		PRECIPITATION																					
		RUNOFF																					
		FLOODING																					
		INFILTRATION																					
		EVAPORATION																					
		MELTING																					
		SPRINGFLOW																					
		STREAMFLOW																					
		TRANSPIRATION																					
	NUTRIENT SOURCE																						
		WEATHERING																					
		MINERALIZATION																					
		DECOMPOSITION																					
	SOIL MICROFLORA																						
		GROWTH/MAINTENANCE																					
		REPRODUCTION																					

PACT MATRIX FOR TERRESTRIAL SYSTEMS: ENVIRONMEN-
PERTURBATIONS AND ECOSYSTEM COMPONENTS AND
OCESSES.[1]

	HYDROLOGICAL												TOPO-GRAPHIC			EDAPHIC						GEOLOGIC			BIOLOGI													
LETION	CHARGE SURFACE H_2O	MAL DISCHARGE SURFACE H_2O	CHEM. DISCHARGE GROUND H_2O	THERMAL DISCHARGE GROUND H_2O	SURFACE H_2O OF FLOW SYSTEM ALTERATION	GROUND H_2O OF FLOW SYSTEM ALTERATION	CHANGE IN SURFACE RUNOFF PATTERN	LEACHING	SEDIMENTATION	TURBIDITY	MIXING OF STRATA	STREAM CHANNEL MODIFICATION	LANDSLIDES	TOPOGRAPHY MODIFICATION	SURFACE RUNOFF PATTERN MODIFICATION	SOIL REMOVAL	SOIL PROFILE MIXING	SOIL TEMPERATURE CHANGE	SOIL COMPOSITION CHANGE	HUMUS CONTENT ALTERATION	EROSION	SUBSIDENCE	SHRINK/SWELL CLAY EXPOSURE	SEISMIC INSTABILITY	VEGETATION REMOVAL	CHANGE IN COMMUNITY TYPES	CHANGE IN SPECIES COMPOSITION	INTRO. OF PLANT DISEASES/PESTS	CHANGE IN NATURAL PHYSICAL SHELTERS	DECREASED WATER SUPPLY	CHANGE IN ANIMAL NUMBERS	CHANGES IN SPECIES COMPOSITION	INTRO. OF DISEASES/PESTS	BARRIER PLACEMENT	WILDLIFE COLLISIONS	WILDLIFE HARASS	IMPINGEMEN	ENTRA

NVIRONMEN-
NENTS AND

PO-
PHIC

EDAPHIC						GEOLOGIC						BIOLOGICAL																							
URE CHANGE	POSITION CHANGE	UMUS CONTENT ALTERATION	EROSION			SUBSIDENCE	SHRINK/SWELL CLAY EXPOSURE	SEISMIC INSTABILITY				VEGETATION REMOVAL	CHANGE IN COMMUNITY TYPES	CHANGE IN SPECIES COMPOSITION	INTRO. OF PLANT DISEASES/PESTS	CHANGE IN NATURAL PHYSICAL SHELTERS	DECREASED WATER SUPPLY	CHANGE IN ANIMAL NUMBERS	CHANGES IN SPECIES COMPOSITION	INTRO. OF DISEASES/PESTS	BARRIER PLACEMENT	WILDLIFE COLLISIONS	WILDLIFE HARASSMENT	IMPINGEMENT	ENTRAINMENT	FIRES									TOTAL

		DECOMPOSITION
TERRESTRIAL AUTOTROPHS	SOIL MICROFLORA	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		DISPERSAL
	MOSSES / LICHENS	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		DISPERSAL
	HERBACEOUS	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		DISPERSAL
	WOODY	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		DISPERSAL
TERRESTRIAL HETEROTROPHS	SOIL MICROFAUNA & MICROFLORA	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT AFFINITY
		DISPERSAL
	PRIMARY CONSUMERS	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT SELECTION
		DISPERSAL
	SECONDARY CONSUMERS	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT SELECTION
		DISPERSAL

TERRESTRIAL HETEROTROPHS	SOIL MICROFAUNA & MICROFLORA	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT AFFINITY
		DISPERSAL
	PRIMARY CONSUMERS	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT SELECTION
		DISPERSAL
	SECONDARY CONSUMERS	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT SELECTION
		DISPERSAL
	HIGHER LEVEL CONSUMERS	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT SELECTION
		DISPERSAL
WHOLE SYSTEM	ECOSYSTEM	
		SUCCESSION
		NUTRIENT CYCLING
OTHER		

[1] THIS MATRIX IS USED AS
ENVIRONMENTAL PERTURBA
TION OF PERTURBATION-PR
AFFECTED WHEN USED IN C
SELECTED ITEMS). NUMERIC
IMPORTANCE OF THE EFFEC
CAN BE USED **FOR ADDITION**

MATRIX IS USED AS A TOOL FOR IDENTIFYING THE ECOSYSTEM COMPONENTS IMPACTED BY NMENTAL PERTURBATIONS RESULTING FROM ENERGY DEVELOPMENT ACTIVITIES. IDENTIFICA- F PERTURBATION-PROCESS INTERACTIONS ENABLES ONE TO SEE HOW COMPONENTS ARE ED WHEN USED IN CONJUNCTION WITH TABLE **4-10** (STANDARD **FORM FOR** DOCUMENTATION OF ED ITEMS). NUMERICAL VALUES CAN BE ASSIGNED **THAT** PROVIDE A RANKING OF THE RELATIVE ANCE OF THE EFFECTS ON THE STRUCTURE AND FUNCTION OF THE ECOSYSTEM. BLANK SPACES USED **FOR ADDITIONS.**

IPONENTS IMPACTED BY
ACTIVITIES. IDENTIFICA-
OW COMPONENTS ARE
FOR DOCUMENTATION OF
ANKING OF THE RELATIVE
SYSTEM. BLANK SPACES

ECOSYSTEM COMPONENTS AND PROCESSES

ENVIRONMENTAL PERTURBATIONS

			METEROLOGICAL																
FUNCTIONAL GROUP	COMPONENT	PROCESS	CHANGE PRECIP. AMT./REL. HUM.	THERMAL EMISSIONS	GASEOUS EMISSIONS	PARTICULATE EMISSIONS	OXIDANT EMISSIONS	STEAM EMISSIONS	RADIOACTIVE EMISSIONS	TRACE ELEMENT EMISSIONS	SALT DRIFT	FUGITIVE DUST	ODORS	NOISE/VIBRATION	GROUND H_2O DEPLETION	SURFACE H_2O DEPLETION	CHEM. DISCHARG	THERMAL D	CHE
DRIVING VARIABLES	ENERGY SOURCE																		
		RADIATION																	
		CONVECTION																	
		CONDUCTION																	
		RERADIATION																	
	H_2O SOURCE																		
		PRECIPITATION																	
		RUNOFF																	
		FLOODING																	
		INFILTRATION																	
		EVAPORATION																	
		MELTING																	
		SPRINGFLOW																	
		STREAMFLOW																	
		TRANSPIRATION																	
	NUTRIENT SOURCE																		
		WEATHERING																	
		MINERALIZATION																	
		DECOMPOSITION																	
	PHYTOPLANKTON																		
		GROWTH/MAINTENANCE																	
		REPRODUCTION																	
		MORTALITY																	
		DISPERSAL																	

Figure 4-16 IMPACT MATRIX FOR AQUATIC SYSTEMS: ENVIRONMENTAL PERTURBATIONS AND ECOSYSTEM COMPONENTS AND PROCESSES.'

HYDROLOGICAL													TOPO-GRAPHIC			EDAPHIC						GEOLOGIC			BIOLOGIC														
ETION	ARGE SURFACE H_2O	AL DISCHARGE SURFACE H_2O	CHEM. DISCHARGE GROUND H_2O	THERMAL DISCHARGE GROUND H_2O	SURFACE H_2O FLOW SYSTEM ALTERATION	GROUND H_2O FLOW SYSTEM ALTERATION	CHANGE IN SURFACE RUNOFF PATTERN	LEACHING	SEDIMENTATION	TURBIDITY	MIXING OF STRATA	STREAM CHANNEL MODIFICATION	LANDSLIDES	TOPOGRAPHY MODIFICATION	SURFACE RUNOFF PATTERN MODIFICATION	SOIL REMOVAL	SOIL PROFILE MIXING	SOIL TEMPERATURE CHANGE	SOIL COMPOSITION CHANGE	HUMUS CONTENT ALTERATION	EROSION	SUBSIDENCE	SHRINK/SWELL CLAY EXPOSURE	SEISMIC INSTABILITY	VEGETATION REMOVAL	CHANGE IN COMMUNITY TYPES	CHANGE IN SPECIES COMPOSITION	INTRO. OF PLANT DISEASES/PESTS	CHANGE IN NATURAL PHYSICAL SHELTERS	DECREASED WATER SUPPLY	CHANGE IN ANIMAL NUMBERS	CHANGES IN SPECIES COMPOSITION	INTRO. OF DISEASES/PESTS	BARRIER PLACEMENT	WILDLIFE COLLISIONS	WILDLIFE HARASSM	IMPINGEMENT	ENTRAIN	FI

AQUATIC SYSTEMS: ENVIRONMENTAL
ECOSYSTEM COMPONENTS AND PRO-

PO- PHIC	EDAPHIC				GEOLOGIC			BIOLOGICAL																	TOTAL
	TURE CHANGE	MPOSITION CHANGE	UMUS CONTENT ALTERATION	EROSION	SUBSIDENCE	SHRINK/SWELL CLAY EXPOSURE	SEISMIC INSTABILITY	VEGETATION REMOVAL	CHANGE IN COMMUNITY TYPES	CHANGE IN SPECIES COMPOSITION	INTRO. OF PLANT DISEASES/PESTS	CHANGE IN NATURAL PHYSICAL SHELTERS	DECREASED WATER SUPPLY	CHANGE IN ANIMAL NUMBERS	CHANGES IN SPECIES COMPOSITION	INTRO. OF DISEASES/PESTS	BARRIER PLACEMENT	WILDLIFE COLLISIONS	WILDLIFE HARASSMENT	IMPINGEMENT	ENTRAINMENT	FIRES			

	NUTRIENT SOURCE	WEATHERING
		MINERALIZATION
		DECOMPOSITION
AQUATIC AUTOTROPHS	PHYTOPLANKTON	GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		DISPERSAL
	PERIPHYTON	GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		DISPERSAL
	MACROPHYTES	GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		DISPERSAL
AQUATIC HETEROTROPHS	ZOOPLANKTON	GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT SELECTION
		DISPERSAL
	MACRO INVERTEBRATES	GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		DISPERSAL
		HABITAT SELECTION
	FISH	GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT SELECTION
		DISPERSAL
	DECOMPOSERS	GROWTH/MAINTENANCE
		REPRODUCTION

AQUATIC HETEROTROPHS	MACRO INVERTEBRATES	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		DISPERSAL
		HABITAT SELECTION
	FISH	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORTALITY
		HABITAT SELECTION
		DISPERSAL
	DECOMPOSERS	
		GROWTH/MAINTENANCE
		REPRODUCTION
		MORALITY
		HABITAT SELECTION
		DISPERSAL
WHOLE SYSTEM	ECOSYSTEM	
		SUCCESSION
		NUTRIENT CYCLING
OTHER		

[1] THE MATRIX IS USED AS
ENVIRONMENTAL PERTURB
TION OF PERTURBATION-PR
AFFECTED WHEN USED IN
OF SELECTED ITEMS). NUM
RELATIVE IMPORTANCE OF
BLANK SPACES ARE FOR

E MATRIX IS USED AS A TOOL FOR IDENTIFYING THE ECOSYSTEM COMPONENTS IMPACTED BY
RONMENTAL PERTURBATIONS RESULTING FROM ENERGY DEVELOPMENT ACTIVITIES. IDENTIFICA-
OF PERTURBATION-PROCESS INTERACTIONS ENABLES ONE TO SEE HOW COMPONENTS ARE
ECTED WHEN USED IN CONJUNCTION WITH TABLE **4-10** (STANDARD FORM FOR DOCUMENTATION
ELECTED ITEMS). NUMERICAL VALUES CAN BE ASSIGNED **THAT** PROVIDE A RANKING OF THE
ATIVE IMPORTANCE OF THE EFFECTS ON THE STRUCTURE AND FUNCTION OF THE ECOSYSTEM.
NK SPACES ARE FOR **ADDITIONS.**

PONENTS IMPACTED BY
ACTIVITIES. IDENTIFICA-
OW COMPONENTS ARE
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